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Framework for Estimating National Economic Development Benefits and Other Beneficial Effects of Flood Warning and Preparedness Systems

IWR

IWR Report 94-R-3
March 1994

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS, WATER RESOURCES SUPPORT CENTER
INSTITUTE FOR WATER RESOURCES
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REPLY TO
ATTENTION OF

June 24, 1994

CEWRC-IWR

MEMORANDUM FOR COMMANDER, Defense Technical Information Center, Cameron Station, Alexandria, VA 22314

SUBJECT: Transmittal of IWR Report 94-R-3

1. Reference AR 70-31.

2. Two copies of IWR Report 94-R-3, "Framework for Estimating National Economic Development Benefits and Other Beneficial Effects of Flood Warning and Preparedness Systems", has hereby been submitted.

3. Initial distribution of this report has been made to appropriate Corps of Engineers agencies. It is recommended that copies of this report be forwarded to the National Technical Information Center.

4. Request for the DTIC Form 50 (Incl 2) be completed and returned to WRSC-IWR.

FOR THE DIRECTOR:

Enclosure

Kyle E. Schilling
Director

FRAMEWORK FOR ESTIMATING NATIONAL ECONOMIC DEVELOPMENT BENEFITS AND OTHER BENEFICIAL EFFECTS OF FLOOD WARNING AND PREPAREDNESS SYSTEMS

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PREFACE

This report was completed under the Flood Mitigation, Formulation, Planning, and Analysis research work unit at the Corps of Engineers Institute for Water Resources (IWR). Mr. Stuart A. Davis is the principal investigator for the research unit. The Flood Mitigation work unit is part of the Planning Methodologies research program, which is under the direction of Mr. Michael R. Krouse, Chief of the Technical Analysis and Research Division at IWR. Mr. Steven R. Cone is the technical monitor of the Flood Mitigation work unit under the direction of Mr. Robert M. Daniel, Chief of Economics and Social Analysis Branch at the Office of the Chief of Engineers.

Mr. Kenneth Zwickl of the Floodplain Management Services and Coastal Resources Branch of the Office of the Chief of Engineers, Mr. Michael W. Burnham, Chief of the Planning Division of the Corps of Engineers' Hydrologic Engineering Center, Dr. David A. Moser, and Mr. William J. Hansen of IWR all provided comments on earlier drafts of this report. Mr. Robert F. Norton provided the technical editing of the document. Ms. Arlene Nurthen was responsible for the document preparation and publication.

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CHAPTER 1 INTRODUCTION

INTRODUCTION

Methods for estimating benefits to flood damage reduction measures are well established. There are, however, contexts in which the estimation of benefits are more difficult. Estimating benefits of flood warning and preparedness alternatives is one of the more problematic contexts that Corps' planners face.

The "National Economic Development Procedures Manual-Urban Flood Damage" prepared by the Institute for Water Resources in March 1988, presents a thorough documentation of flood damage reduction benefit estimating procedures. Chapter IX of the manual provides an introduction to the evaluation of flood warning and preparedness system benefits.

The purposes of this report are to present a conceptual framework for planners to evaluate benefits accruing to flood warning and preparedness alternatives and to demonstrate methods suitable for estimating these benefits under a variety of planning circumstances. This report presents a simplified workable model, consistent with or adaptable to existing evaluation models and tools used by most Corps' planners.

A single definitive approach is not offered in this report. A frequently contradictory literature is reviewed for the insight it offers rather than for the problems it resolves. A great variety of potential benefits are described. Many of them will be impossible or infeasible to estimate for most studies. A basic modeling approach is presented and some suggested uses of the model are offered. In the final analysis, however, professional judgment and experience will continue to play a major role in the evaluation of flood warning and preparedness systems.

Every evaluation is different and there are no set answers. The benefits accruing to a warning and response system depend on a complex of factors. This report considers many of those factors in the hope of providing reasonable estimates of system benefits for a variety of planning circumstances.

AUDIENCE

This report has been written for Corps' planners and others working in flood damage reduction planning and analysis. It assumes a working knowledge of the Corps' planning principles as articulated in the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) (Water Resources Council, 1983) and the National Economic Development Procedures Manual-Urban Flood Damage (Davis, et. al., 1988). It further assumes some experience with methods and tools used to conduct these analyses.

Flood warning and preparedness systems are being considered by an increasing number of communities as one alternative for dealing with flood problems. Compared to structural projects, these systems are inexpensive. A flood warning and preparedness system is more and more becoming an integral

part of any structural alternative. The diversity of situations in which the Corps planner evaluates these systems results in a need for a flexible, yet robust, method for evaluating the systems.

In the remainder of this report, a conceptual framework based on the P&G and National Economic Development (NED) Manual series familiar to experienced Corps planners is built. Though an overview of the benefit estimation procedure is provided, you will not find the details necessary to perform many of the procedures described in this report. For example, the compilation of damage curves is discussed but the methods and tools available for doing this are not described. The reader is assumed to be aware of the variety of programs available for compiling stage-damage curves for a floodplain.

ORGANIZATION OF THE REPORT

Chapter 2 introduces the conceptual framework needed to evaluate benefits of flood warning and preparedness systems. The emphasis is on inundation reduction benefits, the primary benefit type. It begins with a review of the expected annual damage computation to allow us to focus on the role of the damage curve. The effect of warning time on the stage- damage curve is explored. This is followed by discussion in Chapter 3 of the range of behavioral responses to flood warning and preparedness systems contained in the social sciences literature. To understand the effect of these responses on the damage curve one must understand the different points in the flood warning process where things can "breakdown."

Chapter 4 examines flood warning and preparedness system benefits in some conceptual detail. Using an old, but very serviceable, taxonomy the direct and indirect benefits of such systems are considered. Direct benefits are, roughly, benefits to floodplain occupants and indirect benefits are benefits to others. These distinctions are followed up with a discussion of intangible benefits that can accrue to floodplain occupants and others.

The next chapter presents a flood warning and preparedness benefit evaluation model that builds on the familiar hydroeconomic model used by Corps' planners to estimate expected annual damages (EAD). Construction and use of the model is developed by considering a range of options for shifting the stage-damage curve in the model. For example, the model provides for low budget evaluations and for very detailed surveys that consider shifts in the stage-damage curves of individual structures.

Chapter 6 discusses some of the evaluation options for the model. Suggestions are offered on appropriate estimation techniques for a variety of time and budget options. The report concludes with references and two appendices. The first appendix provides a few technical notes on using the model of Chapter 5. The second presents some quantitative estimates of various warning response parameters found in the literature that can be used with the model.

CHAPTER 2
CONCEPTS

INTRODUCTION

This chapter begins with a review of the model used by the Corps to estimate expected annual damages. This model is the basis for estimating inundation reduction benefits, the major category of benefits accruing to most flood warning and preparedness systems. Once the basic model is presented, attention is turned to the stage-damage relationship because of its critical role in estimating flood warning and preparedness benefits.

The second section develops the idea of a damage function. The most important point of this discussion is that even though most analyses tend to consider damages a function of the elevation of water only, damages are determined by more than the flood stage. "Response to flood warning" will be introduced as a variable of particular interest in addition to flood stage, in evaluating flood warning and preparedness systems.

EXPECTED ANNUAL DAMAGES

Expected annual damages (EAD) are typically estimated using a hydroeconomic model familiar to Corps' analysts. Floods are random events that cause damages, hence flood damages are random events. More pointedly, flood damages are probabilistic events. The probability of any specific amount of flood damage depends on the probability of the flood event necessary to cause those damages.

Figure 1 shows the three relationships needed to develop the damage-frequency curve. Figure 1a shows the "damage curve" (aka, stage-damage when representing an entire reach or depth-percent damage curve when representing an individual structure or its contents), a relationship showing damage in dollars realized at varying elevations, or stages, of water. Figure 1b shows the "rating curve" (aka, stage-discharge curve), a relationship that indicates the flow or the quantity of water, usually measured in cubic feet per second (CFS) that it takes to reach varying stages. Figure 1c displays the "frequency curve" (aka, discharge-frequency), which shows the annual probability of obtaining a given quantity of water or greater.

By linking these relationships through their common dimensions[1], it is a simple matter to construct a damage-frequency curve which shows the annual probability of realizing any given level of damages or greater. The damage-frequency curve in Figure 1d is, in essence, a cumulative distribution of flood damages. The mean of this distribution is obtained by integrating the area under the curve. The mean of this distribution is more commonly known as expected annual damages (EAD).

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[1]The stage-damage and rating curves share an elevation dimension. The rating and frequency curves share a flow dimension. The rating curve combines the damage and frequency curves.

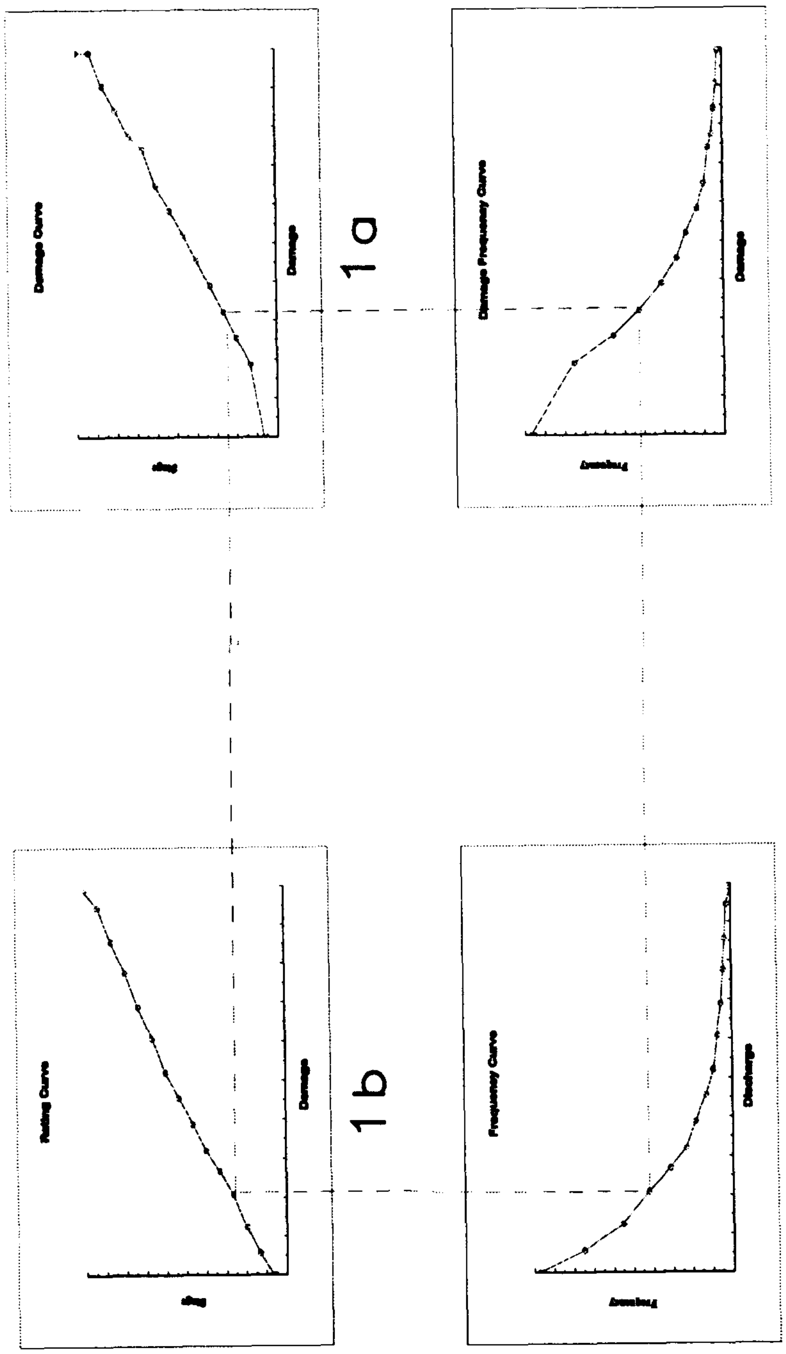

Figure 1
Hydroeconomic EAD Model

The damage, rating and frequency curves are estimated for the without project condition and expected annual damages without the project are estimated. For each flood damage reduction alternative under consideration, these same three relationships are estimated anew. For example, a floodwall or levee project will result in an altered damage curve. A channel project would result in a modified rating curve and a reservoir would result in a new frequency curve. Depending on the alternative, one or more of these three basic relationships will be affected. The new relationships generate a new damage-frequency curve. The expected annual damages obtained from these new relationships represents the with project expected annual damages. The difference between without and with project expected annual damages are project benefits.

THE DAMAGE FUNCTION

Expected annual damage tables for Corps' studies have used the hydroeconomic model described above in one form or another since soon after the 1936 Flood Control Act.

Damages have always been assumed to increase as the depth of water in a reach increases as shown by the stage-damage curve. Nonetheless, it has long been recognized that damages depend on a lot more than the depth of water.

Damages are a function of many variables. Anyone who has ever done a damage survey quickly learns this lesson. Ask a plant manager how much damage he would have with four feet of water and he responds with a series of questions. "How much warning time do I have?" "Does the flood occur at night or during the day?" "Will riggers and trucks be available to remove my equipment?" "Will there be ice in the water?" "What kind of sediment load will be carried?" "Should I assume oily water like last time or clear like the time before?" "My inventory and goods in process vary from day-to-day, week-to-week, and month-to-month with seasonality of my business, what should I assume?" "Do you want conditions for the recession we're in now or for one of our best years?" " What is the duration of the flood?" The questions could go on and on.

STAGE-DAMAGE AND DEPTH-PERCENT DAMAGES CURVES

To develop an understanding of how to evaluate the benefits of flood warning systems, one must first understand the relationship between a stage-damage curve and the depth-percent damage curves of which it is comprised. The damage function discussed in the following pages is presented as if it is the damage function for a hypothetical damage reach rather than for an individual structure. Total reach damage is simply the sum of the damage sustained by each property in the reach. Hence, a stage-damage curve is based upon many individual depth-percent damage curves. Before proceeding to a discussion of the damage function for a reach it is useful to clarify how these damages depend on the damages to individual structures.

Figure 2 illustrates how individual depth-percent damage curves relate to the stage-damage curve for the reach. Though the point will be made again in Chapter 5, it is important to realize that different structures have different possibilities for reducing damages given warning of an impending flood. The changes in stage-damage curves discussed throughout this report are simple depictions of the aggregate changes in the depth percent damage curves of individual structures.

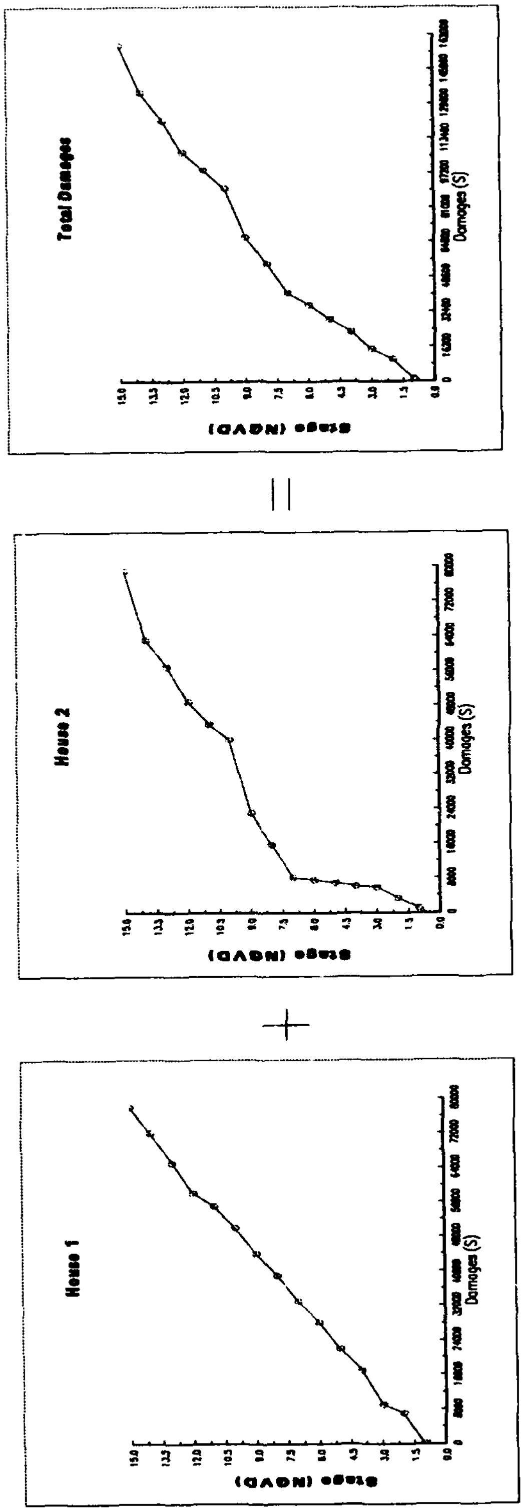

Figure 2
Generation of Stage - Damage Curve

The role of other variables in determining flood damages can extend beyond the concerns of the floodplain occupant. For example, coastal flooding analysts have invented methods of varying ingenuity to account for the fact that wave energy is often more important than the depth of water in determining damages to certain coastal properties. The nature of the event itself is an important determinant of flood damages.

In order to evaluate flood warning and preparedness systems the basic hydroeconomic model is complicated a little, but not too much. In the past, analysts have always recognized that more than one variable determines flood damages (Day, 1969:938). In most cases, the effect of water depth dominates the effect of other variables and for the sake of simplicity, analyses have focused on the relationship between damages and the stage of flood waters.

It is not possible to continue to focus on the depth or stage of flooding variable only, when flood warning and preparedness systems are evaluated. Damages still depend on stage but they also depend on the response of the individual and community to flood warnings.[2] In the next chapter, the nature of flood forecast and warning benefits is considered in specific detail. This section concentrates on understanding the need for a method by which flood warning responses can be evaluated.

The actual damage function can involve dozens of variables and a very complex functional form. A simplified example is used in order to gain some insight into the problems involved in estimating flood warning and preparedness benefits. Consider the simplified general damage function:

(1) D=d(property value, stage, duration, warning response)

Where D is damages measured in dollars; stage and duration are properties of the flood waters; property value is the value of floodplain structures and their contents; and warning response is action(s) taken to prevent or mitigate flood damages.[3]

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[2]This is an oversimplification. Analysts have always dealt with more than two variables in the damage function. Damages at various depths of water vary with the value of the property at risk, the style of structure, etc. and standardized depth-percent damage curves have been developed for certain types of residential structure to allow analysts to account for these variables as well. Thus, though this chapter focusses on the two-variable stage-damage relationship, it is expected that the analyst realizes that the actual practice of flood damage estimating is far more complex.

[3]Effective response, itself, like any of the other arguments in the damage function, can be expressed as a function of other variables. Warning response depends on the flood forecast system considered, the amount of warning time given, the nature of the warning message, the number of people that hear the warning, the number of people that confirm it, etc. A literature review describing some of the variables that affect warning time is presented later in this chapter.

WARNING TIME

The introduction of a new variable, effective response, to the estimation of EAD is the primary purpose of this report. Effective response is the monetized value of effective actions taken by persons to reduce the susceptibility of property and economic activity to damage by floods, between the time of the first public issue of a flood warning until the time a property gets wet or an economic activity is affected.

There are a number of operational difficulties with this definition. First, planners are constrained to considering only those monetized values that contribute to National Economic Development (NED). Losses of income or tax revenues that are critically important to local interests are most often mere transfers of income, from the Federal perspective, and are not NED benefits or costs. This difference in perspective frequently requires the careful education of local interests about what benefits and costs are actually considered in the evaluation of a Federal project.

Second, though it is people who react to warning systems, it is property and economic activity* that account for most of the costs of flooding and for benefits of flood warning systems. It is difficult to empirically link the actions of people to actions that lower the susceptibility of property and economic activity to damage. Very little research has been done in this area.

This report proceeds on the basic assumption that warning systems must effectively reach and convince persons with the opportunity to reduce the susceptibility of property and economic activity to act in a way that produces benefits. For this reason, warning response literature is reviewed to establish the critical links in the process from issue of a warning to taking action.

Finally, warning time is a vaguely defined concept. Figure 3 presents a sequence of time intervals representing major activities that comprise the warning and evacuation process. As the figure illustrates, only a portion of the time from initial detection of a hazard until the water arrives at a property is available in which people can respond. The amount of response time or warning time can vary from property to property, based on a structure's topography. Though the time of first warning is fixed for everyone, water will inundate different properties at different times depending on a property's location in the flood plain. In this report warning time and response time are used interchangeably and it extends from the first warning until water arrives at the first property.

*For example, production of goods and services, transportation and activities commonly recognized as part of our ordinary business enterprise.

Suppose it was possible to estimate this function and it turned out to be the simple linear function, with hypothetical parameters, that follows:

(2) $D = 32 + .02P + 1.1S + .4H - .8W$

- D = flood damages in $1,000s
- P = property value in $1,000s
- S = depth of water in feet
- H = duration of flood in hours
- W = response to warning in hours of warning time

In a traditional flood damage reduction analysis, analysts effectively hold everything but flood depth constant in this function. Let's say the value of the property in the floodplain is estimated to be $1 million. The hydrograph used for the analysis implies a fixed duration of flooding, say, four hours. In actual practice, explicit or implicit assumptions about the duration of flooding and response to warning are made as the damage survey is conducted. These assumptions are reflected in the stage-damage curves and during the damage survey interviews. To facilitate the discussion that follows, assume response to warning is measured in terms of the hours of warning time, in this example 8 hours.

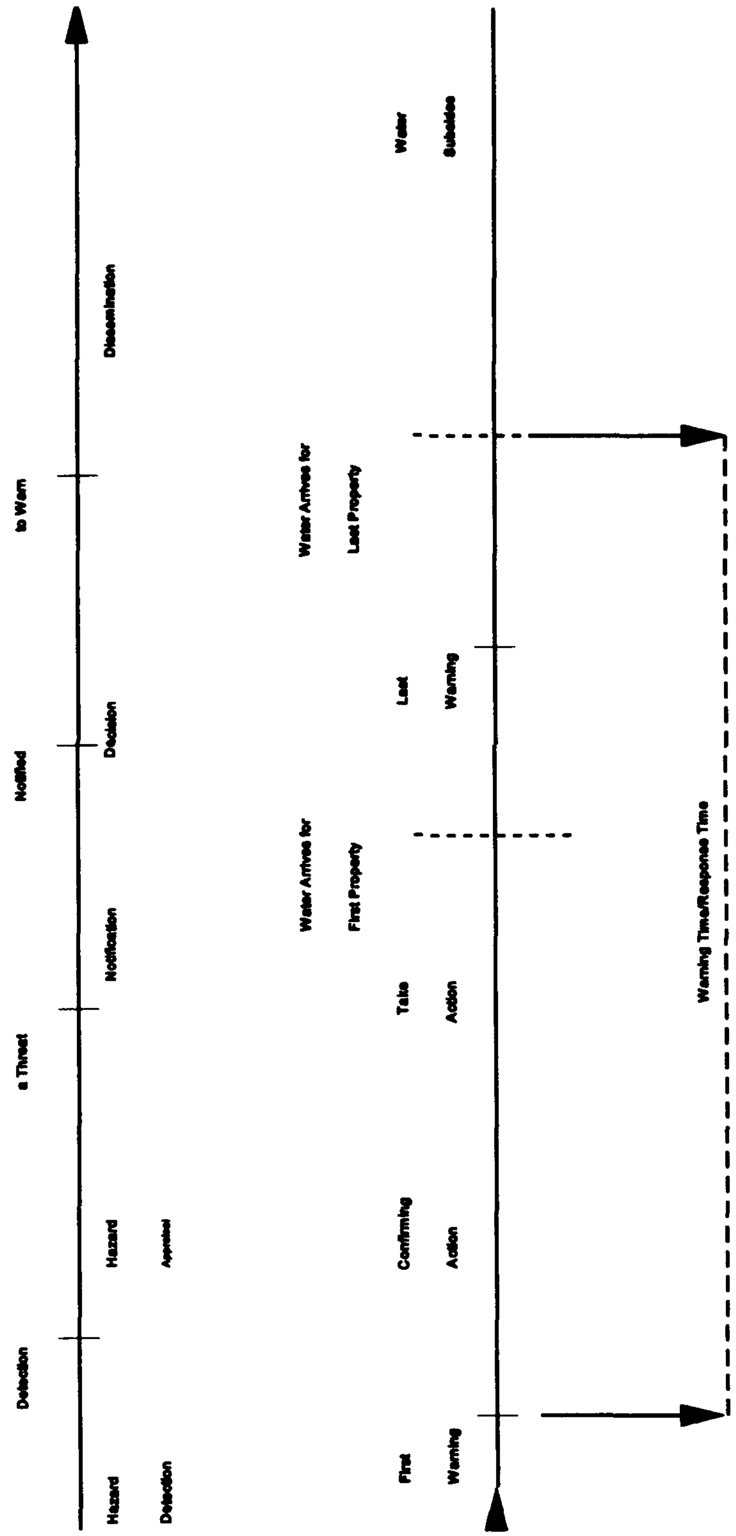

Figure 3
Events and Time Intervals
Associated with Warning Systems

Thus far, values have been assigned to the following variables: P = $1,000, H = 4, and W = 8. Plugging these values into equation (2) a new equation is obtained in which damage is a function of stage only. Equation (3) shows the hypothetical relationship between damages and stage. This relationship holds only for the case where P = $1,000, H = 4 and W = 8. If any of these variables change, the constant in equation (3) will also change resulting in a new damage function.

(3) $D = + 47.2 + 1.1S$

Figure 4 shows the stage-damage curve generated by equation (3). The curve is presented as a linear function, rather than the more typical curve shown in Figure 1a, to keep the analysis simple. Using the curve in Figure 4 and the model previously presented, expected annual damages can be calculated.

Now consider what happens to damages when a flood warning and preparedness system is installed. Staying with the simple linear model of equation (2), assume warning time can be increased to 12 or 15 hours, depending on the warning system implemented. The revised stage-damage functions for 12 and 15 hours of warning are:

(4) $D = 44 + 1.1S$

(5) $D = 41.6 + 1.1S$

These functions are shown, along with the without project condition, in Figure 5.

Changing the warning time results in an entirely new stage-damage curve, hence unique estimates of expected annual damages with the project and project benefits. Changing any of the variables that are normally held constant will cause a shift in the entire demand function and new benefit estimates. The change in this example is a parallel shift because a linear damage function was assumed. The fact that the actual damage function is likely to be far more complicated than the one in our example only makes the nature of the shift more complex, it does not change the fact that a shift occurs.

For every possible response time there is a unique stage-damage curve, all other things equal. If duration or property value is changing in addition to response to warning, the number of new functions quickly becomes unmanageable. Hence, response to flood warning and preparedness alternatives are evaluated by only slightly relaxing the model and allowing response time to change, all other things equal. In effect, it is assumed that the duration of flooding remains four hours and the property value is fixed at $1,000,000 for all the possible response times.

The damage function of interest in our example becomes:

(6) $D = 53.6 + 1.1S - .8W$

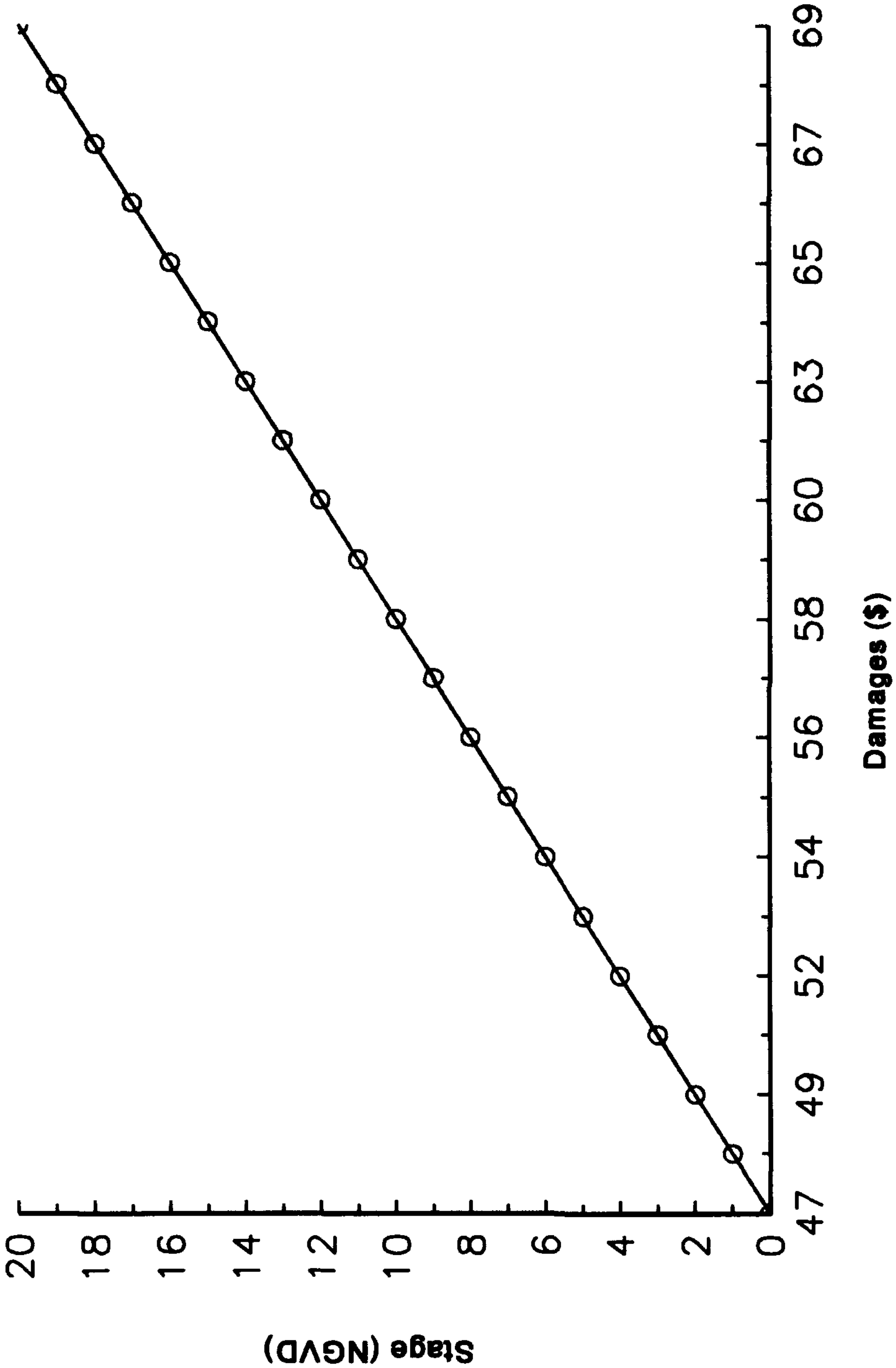

Figure 4

Linear Stage-Damage Curve

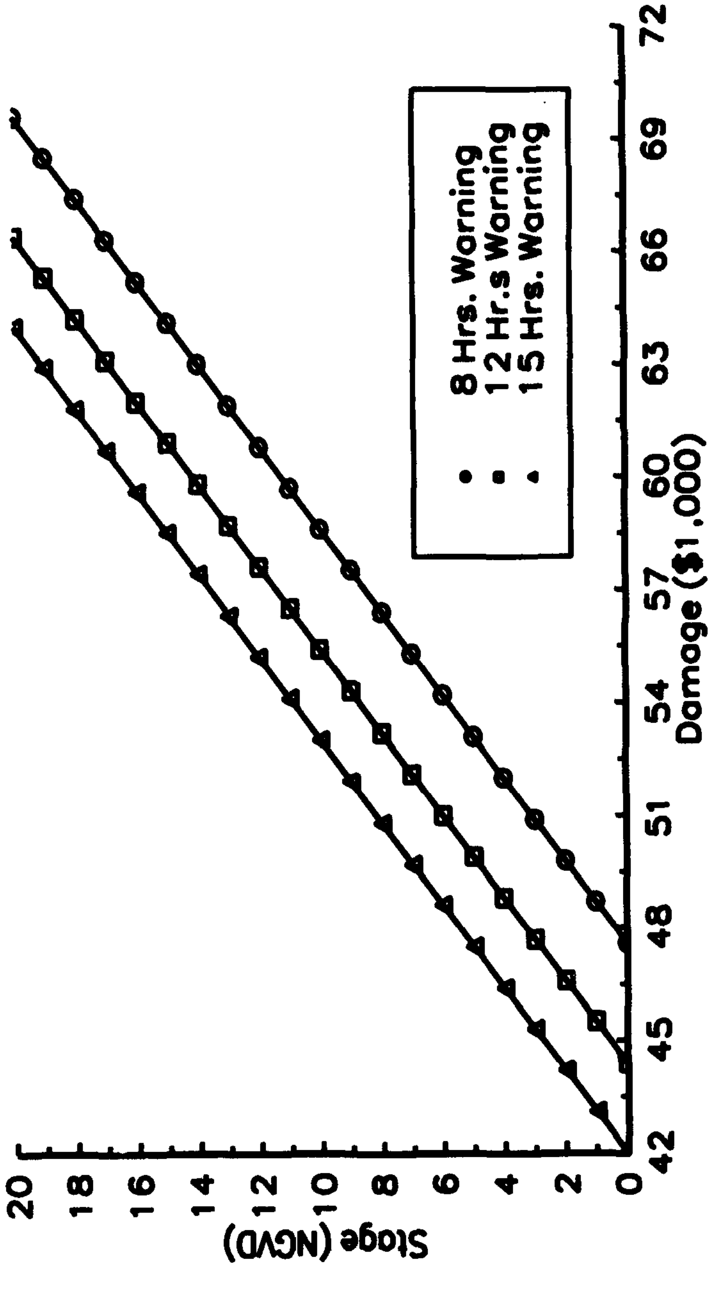

Figure 5

Shifting Linear Damage Curve

This is a three-dimensional function as shown by the plane surface in Figure 6. The true damage function may never be known, but it is almost certainly far more complex than the linear function used here. The response to warning time is likely to be nonlinear.

Figure 7 shows a nonlinear function of damages, stage and response. Response time reduces damages as the level of flooding increases, but only up to the point at which stage becomes the dominant factor. Figure 8 shows curves in stage and warning space that result in the same amount of damage, derived from the three dimensional function of Figure 7. The height in Figure 7 is the damage dimension. If a slice is cut through the function at any given height, i.e. a specific amount of damage, parallel to the depth-warning axes, all the possible combinations of flood depth and warning time that can result in identical amounts of damage are contained on that slice.

By cutting a slice of the three dimensional function parallel to the stage-damage axes, a stage-damage curve associated with a given amount of warning time is obtained. Change the warning time and you move to a new location in the warning dimension. Cut another slice of the function and you obtain a second stage-damage curve. Thus, a shift in the stage-damage curve that results from a change in warning time is the same as moving to a new position on the three-dimensional function. Figure 9 shows the damage curves that result from different amounts of warning time.

These "slices" projected in two-dimensions are simply contours. Contours are routinely used to show three dimensions in two-dimensional space. Topography maps are the most common example. Topographic maps show distance in the north-south, east-west directions and height is given by the value associated with the contours. These contours are simply "slices" of the terrain under examination.

Estimating the effects of a flood warning and preparedness system can be more or less complicated. Dealing with a function as shown in Figure 7, the mathematics can become very complex, assuming the actual function could ever be identified.

A pragmatic alternative is to identify a range of reasonable alternative functions and complete the analysis over that range of alternatives. For example, Figure 5 shows stage-damage curves for three different response times. Each response time will produce a different estimate of expected annual damages. An appropriately weighted mean of these expected annual damages is a reasonable approach to estimating the variable effects of a flood warning and preparedness system. This technique is extended and explained in detail in Chapter 5.

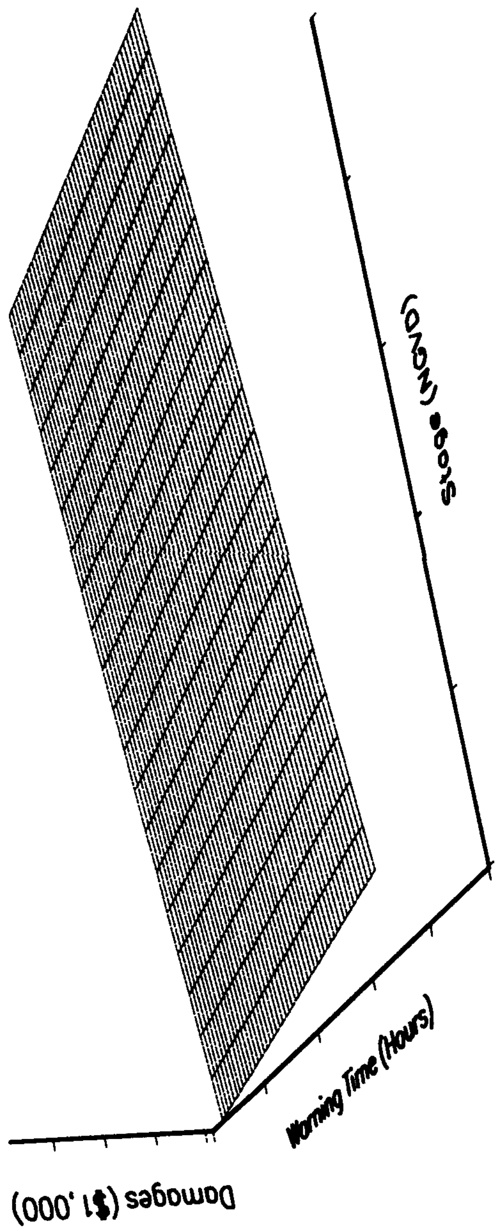

Figure 6

Linear 3-D Damage Function

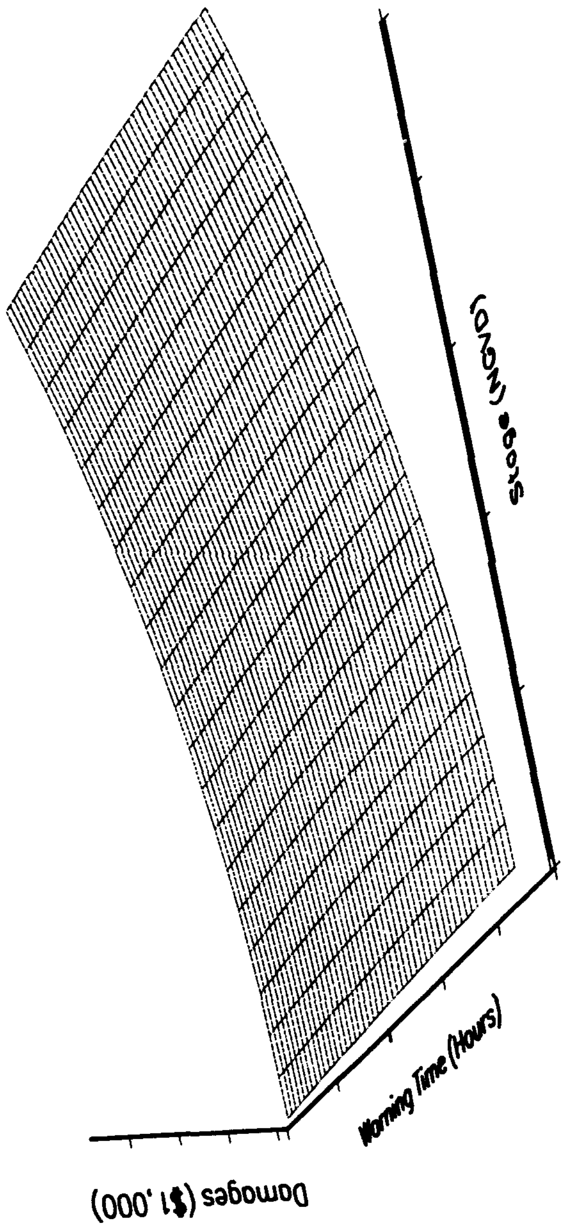

Figure 7
Non-Linear 3-D Damage Function

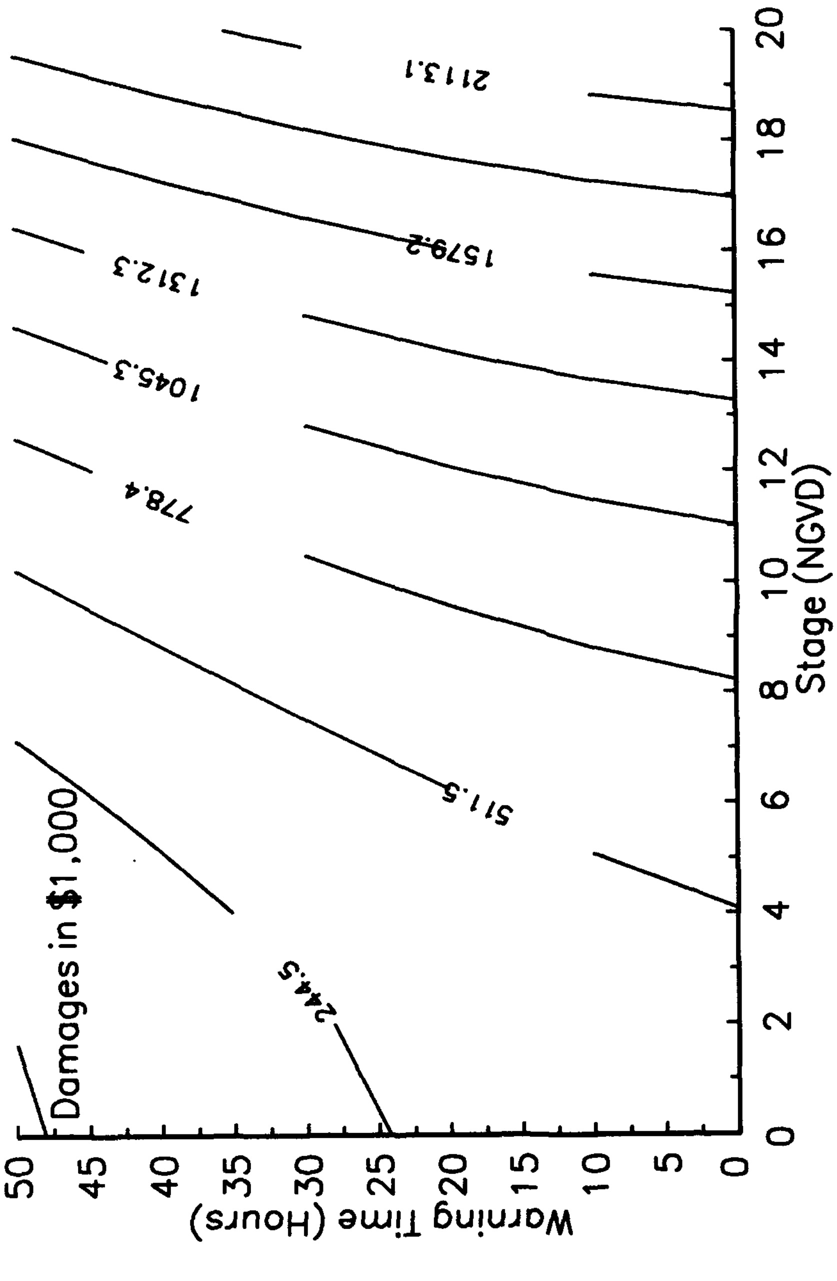

Figure 8
Damage Contour in Stage - Warning Space

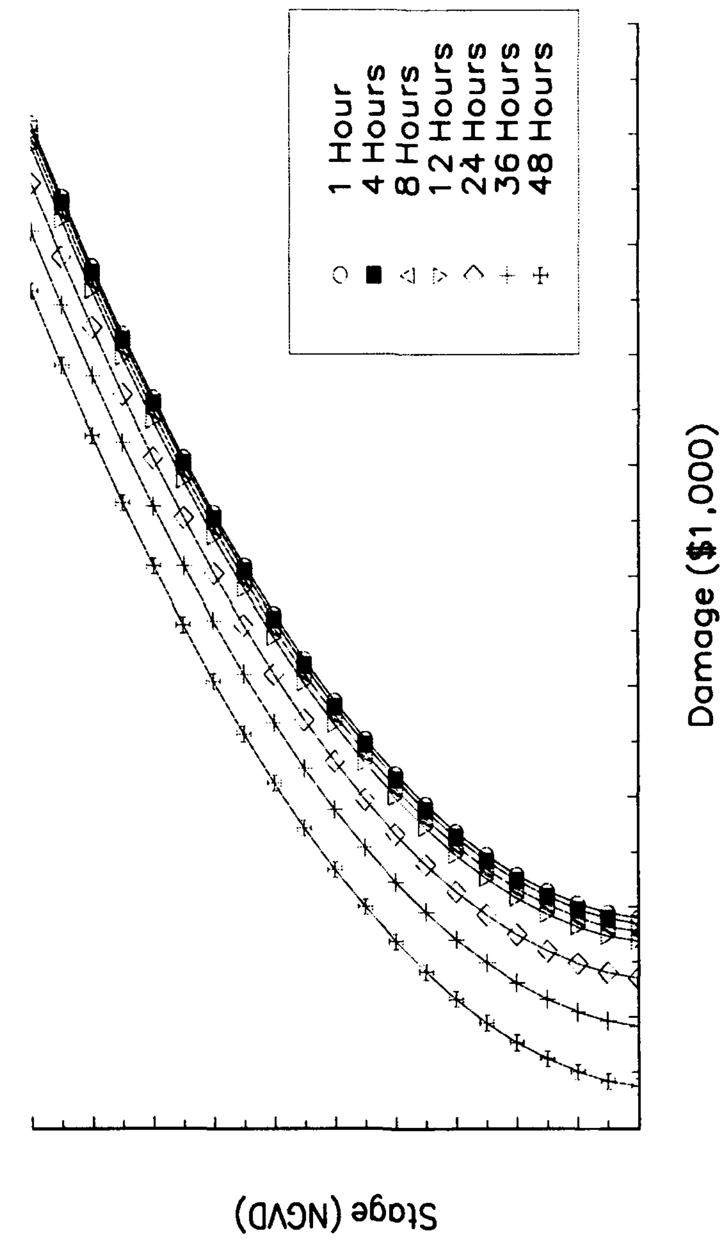

Figure 9

Warning Contours in Stage - Damage Space

CHAPTER 3
BEHAVIORAL RESPONSE TO FLOOD WARNING AND PREPAREDNESS

INTRODUCTION

The extent to which a damage curve shifts as a result of a flood warning system depends entirely on the behavioral response of the individuals at risk from flooding. When people respond to a warning, they may take steps to minimize their damage from the impending flood. The cumulative effect of these actions is a shift in the depth-percent damage curve for the contents of a structure that reduces damages as compared to the without project, e.g., no flood warning and preparedness system, condition. The accumulative shift of the individual curves causes a shift in the stage-damage curve.

To estimate benefits you need to know how the damage curve shifts. To know how the damage curve shifts requires knowledge of how people respond to the warning. This is a complex issue, the resolution of which is well beyond the scope of this report. In this section, a flood warning system is seen as an ongoing process. The process is described so analysts can see the potential for behavioral responses at different points in the process that can affect the shift in the individual or aggregate demand curves.

Flood warning and preparedness systems are often unbalanced, in that attention can be focussed on the hardware required for warning and response dissemination with little consideration given to development of a formal response plan. The response phase of a system is critical to the determination of benefits. Thus, the benefits of flood warning and preparedness systems described of this report are entirely dependent on the behavioral aspects of the system that determine or affect individual and community responses to a warning.

Behavioral responses can be considered among the variables that determine the effect of the warning response variable shown on the three-dimensional damage surfaces presented in Chapter 2. For example, more effective warning messages will result in less damage at any depth of water, all other things held equal. Though the mathematical dimension of the evaluation concepts will not be pursued further, it is not difficult to see that the extensive literature on warning systems fits the evaluation context presented above rather nicely, once behavioral responses are seen as arguments in the damage function.

What is missing from the literature is reliable information about what actions people do or do not take that may reduce their susceptibility to flood damages after hearing a warning. There is an abundance of data describing initial reactions, how many people heard a given warning, etc. Evaluation of flood warning systems requires some knowledge of the actions people take to avoid damages and there is a dearth of such information. Until more information becomes available, analysts will have to rely on inferences from the existing data, their own experience, and area-specific survey results.

There is a voluminous literature on behavioral responses to warnings of all types. The bulk of the literature has developed around natural disaster warning systems, chiefly hurricanes and floods. Before the analyst can provide a quantitative answer to the question, "How much does the damage curve shift?" the

analyst needs a clear understanding of the nature of individual and community responses to warning systems. While there is no substitute for experience in gaining this understanding, the literature goes a long way to facilitate that understanding.[4]

Figures 6 and 7 depict damages as a function of water depth and warning response. In actuality, warning response is, itself, a function of numerous variables. The literature review that follows examines some of the variables that determine warning response. The reason for doing so is that changes in these variables change warning response, which in turn shifts the damage curve. Thus, the literature is considered to learn what it is about a community that affects the shift in its damage curve.

The link between the literature and an effect on the damage curve is not a direct one. You will not find specific recommendations or empirical results instructing you in how much to shift a damage curve. This is a context contrived for this report; intended to help analysts make judgments about whether the warning response in a project area will be greater or lesser, depending on the extent to which conditions described below exist in a project area.

The paragraphs that follow present research findings that, at times, are contradictory. At other times, the findings may be so specific as to seem trivial. The utility of these research findings will become more evident when the model for estimating flood warning and preparedness benefits is presented in Chapter 5 and when empirical results from the literature are presented in Appendix 2. Many of the results that follow here and in the appendix can be used to set the ranges of key variables that can be used with the model.

The presentation that follows, closely follows the presentation method employed by Drabek in his book. It begins by defining warnings as a process. In this context, the warning process encompasses all of the events and time intervals presented in Figure 3. The review concentrates on those events that are typically part of the public warning process. This includes initial reactions to warnings, the content of the message, qualities of the persons hearing the message, and the very important stage of confirming behavior. The remainder of the review concentrates on evacuation issues; specifically what people do before evacuation and the rates at which they evacuate.

ORGANIZATIONAL RESPONSE

The literature identifies the most important variables as the speed with which warnings are issued to the public (i.e., response time) and previous disaster history. Experience tends to result in less skepticism and more effective action. Sorenson and Mileti (1987) reviewed accounts of 39 disasters and

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[4]Though there is an extensive literature, two works are singled out for special attention. Human System Responses to Disaster: An Inventory of Sociological Findings, by Thomas Drabek, provides exceptional access to the literature in a well organized and documented review of the literature through the early to mid eighties. Drabek's work appears to build on the earlier effort, Human Systems in Extreme Environments: A Sociological Perspective by Dennis Mileti, Drabek, and J. Eugene Haas.

identified 19 specific categories of uncertainties in organizational decision-making. Their review makes explicit the many areas in which the warning process can falter from the time a disaster has been detected until the warning is disseminated to the public.

The detail of this and other work points out the need for planners to deal with reasonable simplifying assumptions. The planners' knowledge of the study area is of the utmost importance in deciding which factors can be safely ignored, assumed constant, or in need of explicit handling.

The literature shows that community planners should be aware of certain factors, many of which will be reviewed here, that will affect public response to warnings. Corps' analysts are also well-advised to be aware of the presence of these factors in the warning system under consideration. Drabek (1986:93) summarizes these factors more generally as:

1. The warning must be clear;
2. The warning must convey what is the appropriate response;
3. The warning must be perceived as coming from a credible source;
4. The warning must be reinforced socially and at the local level;
5. The medium used to disseminate the warning is important; and,
6. The type of appeal must be considered and assessed.

Systems that address these concerns will result in larger shifts in the damage curve, all other factors equal, and NED benefits will be larger the more a community's warning system adheres to the above factors. Though little of this kind of work is included in most warning system planning studies, the literature suggests it would be wise to do so. It would appear that benefit estimates can be increased as communities attend to more and more of these factors.

DISASTER WARNING AS A PROCESS

Researchers have argued, since the 1950s, that disaster warnings must be regarded as a social process. Worth and McLuckie (1977) have developed a model of this process consisting of three stages: forecast, alert, and confirmation. Though there are many alternative model formulations they all share the same basic elements.

The forecast stage is evaluative. In this stage, forecasting technology plays the greatest role. Events are detected and measured as data are collated and interpreted. Once the potential for, or nature of, a disaster has been determined, someone must decide who to warn, what to warn them about and how to warn them. The final step of the forecast stage is the transmission of the warning.

In this report, for purposes of developing benefit evaluation techniques, it is assumed that the forecasts are accurate and the system is dependable. While this is clearly not going to be true in all cases, addressing the situations in which this is not true unnecessarily complicates our treatment of the topic without adding any additional insights. The model presented in Chapter 5 could be modified to reflect uncertainty about the system's accuracy or reliability in the forecast stage, though this is not done.

The alert or warning stage is where most decisions are made. It begins as the forecast stage ends, with decision makers deciding who should be warned about what danger and in what way. Speed is the key to warning. The more warning time that is provided the more time there is to respond. Warning messages need to be clear, complete, specific and non-technical. There is a crucial trade-off between timeliness and accuracy. The longer one waits to issue a warning the better the available information on which to issue a warning will be, but the less time is left for people to respond to the warning. Warnings given quickly provide maximum response time, but they run the risk of costly over-reaction to preliminary forecasts or to false warnings.

The third and critical stage, from the perspective of estimating flood warning and preparedness benefits, is the confirmation stage. Technology dominates the first stage, decision makers the second, and the reaction of the individual dominates the confirmation stage. People need to be able to confirm the warning and get additional information. The extent to which an individual believes the information that is received depends largely on his ability to confirm that information. People need a second message that says, this is really it!

Warnings must give behavioral advice as well as factual information. Hence, flood fighting and other individual responses to a warning depend critically on confirmation of the message.

During the confirmation stage the message is interpreted. Receivers of the message offer feedback to the message providers ("Sheriff, is it true the Sleepy Hollow dam broke?") and the message may be revised as necessary. ("The dam did not break but residents of Sleepy Hollow have evacuated to the county high school.")

Flood warning and preparedness benefits depend on the quality of the forecast, the effectiveness of the alert, and the individual response. Only the last two of these stages of the warning process will be addressed in this report.

Keeping in mind the warning system is a social process, Mileti's notions about how people respond to warnings are useful:

> "1. Even though several persons may listen to the same warning message, there may be considerable variation in what they hear and believe; 2. People respond to warnings on the basis of how what they hear stimulates them to behave; and, 3. People are stimulated differently depending on who they are, who they are with, and who and what they see." (Mileti, 1975:xvi)

Drabek says:

> "Individuals exhibit a tendency of inertia. That is, no behavioral action will be directed toward a warning response until a sequence of information-processing steps have occurred." (Drabek, 1986:71)

The conclusion drawn is that shifts in the damage curve must take into account the fact that warning response is a social process. It is not sufficient to assume for simplicity that everyone hears the warning and takes appropriate action. Such assumptions, though adequate for theoretical work, are inappropriate for evaluating the benefits of flood warning systems.

Every warning system should include elements that specifically address the range in behavioral responses of the community. The following literature review suggests some behavioral responses and community characteristics that should be considered in developing a plan. Any plan that ends with the installation of hardware and identification of the person who is to issue a warning is only half complete.

INITIAL RESPONSES

One of the most widespread disaster myths is that, when warned of an impending disaster, the public will panic. Time and again, research shows that, quite to the contrary, the public's primary reaction to such warnings is disbelief.

> "..most people's immediate reaction to the first warning received is disbelief and a continuation of normal routine." (Perry, Lindell and Greene, 1981:153)

This "normalcy bias" is an attempt to neutralize the threat. This phenomenon would tend to suggest there is a built-in bias toward not taking any immediate action upon receiving a warning. In situations where warning times are short, this normalcy bias will limit the extent of damage mitigating activities. Other things equal, short warning times will result in smaller shifts in the damage curve.

We will see in subsequent paragraphs that there are circumstances that mitigate this normalcy response. The literature is, unfortunately, devoid of multivariate analyses that indicate the cumulative effects when a number of variables, considered individually important, are present. Thus, we know little about how people will react in a situation where one factor alone results in inaction and a second factor alone normally results in some action.

The literature consistently shows an initial reaction of denial. People believe they are not in immediate personal danger until they are unable to continue in this belief (Quarantelli, 1980b:107). Members of threatened communities will seize upon any vagueness in the warning message to reinterpret the situation in a non-threatening manner (Greene, Perry and Lindell, 1981:60).

> "What must be stressed is the diversity in response. There is no uniform pattern." (Drabek, 1986:73)

Due to the diversity of initial responses to warnings, global assumptions about a project area's response to flood warnings are to be avoided whenever possible. There is no basis in the literature to support an assumption that 100 percent of a community or group of people will respond in any one way. Thus, adjustments to damage curves should account for the fact that not everyone responds in the same way. This can be done rather simply by, for example, assuming 70 percent respond in one way and 30 percent respond in another; the result being a weighted average of the two responses.

A second point that would seem to arise from the inertia inherent in the normalcy bias and denial stages of initial response is that people will not use the entire warning time available to them for mitigating damages. They will be engaged in confirming activities for some of that time. Thus, a four hour warning time does not mean that people will spend four hours mitigating their damages. Taking these factors into account will result in smaller shifts in the damage function than would otherwise occur.

MESSAGE QUALITIES

The content and quality of the warning message, though not independent of the sender or receiver, have proven important in evoking common response patterns. With regard to qualities of the message, Drabek finds:

> "Three qualities have been found to matter: (1) content; (2) source; and (3) number." (Drabek, 1986:74)

It has been found that both personal risk and belief in the truth of the warning are positively related to warning response (Perry and Greene, 1983:101). Those closest to the river would tend to take more action that those somewhat removed. This fact would provide justification for analysts to consider expected annual damage computation reaches based on relative risk (for example, assuming greater shifts in the damage curve of occupants of the 10-year floodplain than for occupants of the 50-year floodplain suggests developing a separate stage-damage curve for structures in the 10-year floodplain), rather than traditional hydraulics and hydrology or damage considerations, in certain cases.

Specific messages from sources with high credibility sent out repeatedly prove to be most successful in evoking an appropriate response. This becomes important in evaluating the benefits of a warning system. Most warning and response systems concentrate on getting the hardware into place with the rudiments of a communication network outlined. Little thought is typically given to the quality of the message. The literature suggests that when a message is specific, credible and frequent the damage curve shifts more, all other things equal. The more carefully the system is planned with regard to the message quality, the greater the shift in the damage curve.

The best warning messages must be personal, specific, unambiguous, prescribe appropriate measures, be issued by a credible source and distributed by several media. Messages should also account for existing beliefs and attitudes toward the hazard whenever possible and provide opportunities for confirmation (Rowsell, 1978). Neal and Parker (1989:54) conducted a study of customer response to, and satisfaction with, selected flood warning systems in England. They found:

> "..it is important for flood warning messages to impart 'behavioral' information as well as factual information."

Warning systems that devote attention to these warning characteristics will provide more opportunities for reducing damages prior to flooding. Shifts in the damage curve will be greater in communities where the message is specific, the provider of the message has credibility, and the message is repeated frequently

through a variety of media. Plans that do not address such details can be expected, other things being equal, to result in smaller shifts in the damage curve and fewer benefits.

DEMOGRAPHIC QUALITIES OF WARNING RECEIVER

Different responses to flood warnings have been documented among different categories of persons. While it is clear that characteristics of those who receive warnings do matter, it is not always clear how they matter.

People experienced with flooding situations tend to take warnings more seriously and begin to react sooner than others. They are also more likely to evacuate (Perry, Lindell and Greene, 1981:153). Thus, given two communities alike in every respect except that one has had recent flooding and the other has no flood history, one can expect a greater shift in the damage curve of the experienced community to result from a warning and response system. There is always some danger that people will overestimate their experience[5], however, causing the experienced community to fail to react appropriately.

Experience is a factor that can also work to minimize the shift in a damage curve, if the experience has been negative.

> "..if warnings are issued and events predicted do not materialize, the consequence of the experience may be to neutralize future warnings. Thus a "cry-wolf" syndrome may emerge." (Drabek, 1986:77)

Parker and Neal (undated), on the other hand, found the empirical results of their 1986-7 research on warning systems:

> "..suggest that flood victims would rather receive a warning than not receive one, even if flooding does not follow."

Sims and Bauman (1983:173) assert that many natural hazards are rather rare events and:

> "..people can be mislead by their experience because that experience is limited or biased; it does not constitute an adequate sample."

Carter (1979) found that people without hurricane experience evacuate earlier than those who have experienced a hurricane. The latter group waited for total confirmation of the necessity for evacuation. Hence, the assumption of experience leading to greater reaction and larger shifts in the damage curve must be tempered by specific knowledge of the study area population.

[5]"Hurricane parties" are frequently reported phenomena that could result in disastrous consequences. Individuals who believe they have weathered worse storms fail to evacuate in the belief they can weather this storm, too.

Demographic characteristics of a population have, individually, been shown to be important in determining response to warnings. If you know the composition of the floodplain population, it may be possible to make better judgments about whether to shift a damage curve more or less based on what is known about certain groups' behavior. For example:

> "There appears to be a tendency for persons of low and high education to disregard the formal meaning of a signal, while persons of middle socio-economic status are more likely to accept the formal meaning." (Mileti, Drabek and Haas, 1975:47)

The implication is that both wealthy and poor communities are less likely to act as effectively as middle-class people are. This suggests larger shifts in the damage curve result in middle-class communities than in higher or lower income communities, all other things equal. Women are more likely to interpret a signal as valid than are men (Mileti, Drabek and Haas, 1975:47).

While some argue that the elderly are more reluctant to believe warning messages, it appears clear that the elderly are less likely to receive the message in the first place. Thus, damage curve shifts in communities with a large elderly population are likely to be smaller than in other communities. Physical ability of the elderly to take mitigating actions would appear to be another limiting factor, Neal and Parker (1989) found:

> "The evidence suggests that a major reason for flood warnings not leading to higher levels of flood damage reduction is the physical inability of the elderly and others in the community to respond adequately to a flood warning."

They further suggest that emergency preparedness plans should recognize this fact and plan to assist the elderly. Plans that heed this warning would seem to be justified in assuming larger shifts in the damage curve.

Small town residents and people from small town backgrounds are less likely to interpret warning messages as valid than are urbanites (Mack and Baker, 1961). The closer people are to the threatened area, the more seriously they take the message (Diggory, 1956). Tightly knit and active communities tend to respond more (Drabek and Boggs, 1968), a possible contradiction of the small town finding above.

Though there is little evidence on response by racial group, Turner (1976:183) found:

> "..members of minority groups will assign little credibility to the official sources that disseminate warnings, and consequently will not be predisposed to take appropriate precautionary actions."

This is consistent with the earlier reported finding that stressed the importance of the credibility of the message giver. A number of studies have shown that individual hazard behavior is related to people's limited capacity to process information. Slovic (1980) has shown that people use certain rules of thumb in estimating risks, and these are not always accurate tools. For example, if a series of coin tosses has

resulted in six heads in a row, it is human nature to assume the seventh toss has more than a 50-50 chance of being a tail. It does not. Similarly, people who have experienced a 100-year flood tend to believe that flood will not be experienced again in their lifetime and most certainly not in the next year, despite the fact that the probability of such a flood is undiminished.

Taking several of these demographic findings together, one might expect that small town communities of elderly, minority men will respond less to flood warnings (hence, a smaller shift in the damage curve) than would an urban middle-class community of young white women. Though this comparison is offered tongue-in-cheek, the point is nonetheless valid.

CONFIRMATION BEHAVIOR

As mentioned earlier, people do not panic when they receive a disaster warning. They tend to disbelieve the message. As a result, the most probable reaction of people receiving a warning is to try to gather additional information. They are, in essence, seeking to either confirm or neutralize the warning. Assuming the warning to be a true one, confirmation behavior becomes important in the warning process. It is equally important to the analyst because confirmation takes time and time is a critical determinant of shifts in the damage curve.

Perry, Lindell and Greene (1981:28) describe the major processes involved in behavior following receipt of a warning. The initial confirmation process focuses on gathering additional information. This information comes from talking to family, neighbors, co-workers; calling officials; listening to the media; and, personally investigating (e.g., looking at the river), among other things.

The second stage of the confirmation process focuses on assessing personal risk. Once a person believes the message, he must determine his proximity to the impact area (floodplain) and assess the certainty of the threat and its probable severity. All of this confirming activity takes time. In situations where there is plenty of warning time this may be of little consequence. In areas with little warning time, confirming activities can reduce the available response time substantially. The shift in the damage curve is assumed to increase with warning time, all other things equal.

The timing of the warning can also be an important factor in confirming behavior. Time of day, week and year can affect the individual's ability to confirm a warning through alternative sources. A warning heard over the radio at 3 a.m. cannot be easily confirmed by neighbors. Neal and Parker found that "customers" of warning systems consider it a high priority to receive warnings during the daylight hours.

Warnings given during the day when families are separated can slow down the response actions of people.

> "..unless all members are accounted for, families will be slow to undertake any kind of protective action." (Perry and Greene, 1983:66)

Families tend to act as units, taking mitigating or evacuating action together. It is more likely they will take no action when they are separated. The significance of this for damage curve shifting would appear to lie in an assessment of how easy or difficult it would be for families to reunite during an emergency. Damage mitigating activity is more likely once the family is reunited. In a small town where jobs, home and schools are geographically close this will be less difficult than in a large urban area where things are more spatially dispersed.

Worth and McLuckie (1977) reviewed the warning process in a number of Colorado communities flooded in June 1965. They found three basic responses to warning: immediate response to warning, attempts to confirm the warning, and ignoring the warning. Confirmation took the form of appeals to authorities, e.g., calls to local authorities, radio and tv stations. Appeals to peers, i.e., families, friends, neighbors, etc. were also common confirmation behaviors. These appeals were a poor source of factual information.

Observational confirmation was frequently used in the Colorado floods. People went to the river or watched their neighbors' actions. The fourth confirmation technique was inadvertent confirmation, an unintentional or accidental way of confirming the flood, for example, by observing a road closed by flooding.

Confirming the flood was important in each case and the confirmation problem becomes bigger if there is not enough time to complete the confirmation process. Neal and Parker say:

> "..the customer's need to confirm flood warnings, once received, appears to be very important to the damage reduction process. Systems designed to provide telephone callers with a confirmatory service should be maintained.."

Thus, plans that provide explicitly for confirming behavior can be expected to result in more damage reductions. Of importance to planners is that time spent confirming a warning is time taken away from damage mitigating activities. Thus, confirmation opportunities should be provided to facilitate the most timely completion of the confirmation process.

PRE-EVACUATION RESPONSES

After receiving a warning, the pre-evacuation response, i.e., the activities that could lead to a reduction in damages, depends on the factors reviewed above. The question of most interest in this report, i.e., what do people do with their time before they evacuate, is not addressed in the literature. Little, if anything, has been done to determine what people do between the time they confirm a warning message and the time they evacuate. This does not bode well for analysts who want to know how to adjust damage curves. Recent work by IWR and a few other sources providing some quantitative estimates of behavior responses is reviewed in Appendix 2.

We pay particular attention to the literature on evacuation response for two reasons. First, evacuation is a critical response in any effort to reduce the potential for loss-of-life due to flooding. The

second reason is purely a conjectural one on the author's part, unsubstantiated by any empirical evidence. We are inclined to believe that once people become convinced of an impending disaster, particularly people who voluntarily evacuate the impact area (i.e., floodplain), they will take action to mitigate the effects of the disaster before they evacuate. The reader is cautioned, that despite the common sense appeal of this argument, it is speculation and not an established fact.

Carter (1977) found that in two communities

> "..the "earliest leavers" are those experienced with hurricanes and who do not feel that staying will contribute to the protection of their property (e.g., from direct damage or looting)."

This finding contradicts the subculture of experienced hurricane veterans determined to stick it out at any cost. It also indicates that hurricane behavior and flood behavior may differ in significant ways when it comes to behaviors that influence the shifting of a damage curve. No evidence has been found to support the existence of "early leavers" in the floodplain, those pessimistic about their ability to limit their damages.

Ferrel and Krzysztofowicz (1983) define an individual's degree of response to a warning system as a function of the degree of response already undertaken, the number of warnings, the current flood level, and the forecasted flood crest. The latter of these two is obtained from the forecast.

EVACUATION RATES, REASONS, AND FACTORS

Worth and McLuckie identified four types of individual evacuation decisions during their study of the Colorado floods. First, there is evacuation by default. People who went to work, shopping, to comfort a neighbor, etc. are unable to return to their homes because of rising waters or roadblocks. Second, is evacuation by invitation. Family or friends express concern and ask a resident to leave the hazard area. Evacuation by compromise, the third type, results when a member of a family leaves to placate other members of the family. The most commonly thought of evacuation type is evacuation by decision, i.e., an evacuation order is given by an authority or, in the absence of a formal authority, a family or organizational head decides to evacuate the floodplain.

Images of mindless hysteria and countless auto accidents have not been documented in the literature (Drabek, 1986:123). The research indicates that some communities begin to 'specialize in their disasters' (Wenger, 1972:39) and develop subcultures for coping effectively with them. Strope, Devaney, Nehnevasja (1977:4) reviewed 228 events where evacuation occurred and found:

> "...the average hurricane evacuation has involved about 40,000 evacuees as compared with about 4,000 in other types of disasters."

The available research shows that when people are properly warned they do evacuate in large proportions. Perry, Lindell and Greene (1981) indicate that approximately 50% of the population, threatened by a natural disaster, will evacuate upon receiving an official advisory. In volcano eruption studies 11.1% of the population has failed to evacuate. At Three Mile Island, 39% of the total population

within 15 miles of the reactor, evacuated (Perry, 1983:43). Carter (1979) found that at least one-third of the public will not automatically follow official evacuation orders. However, 90% will evacuate if convinced of the seriousness of the threat.

People are generally motivated to evacuate when they see the hazard, are urged to by officials or relatives, or when their neighbors leave (Perry and Greene, 1983:89). Fear of looting is frequently given as a reason for not evacuating (Perry, 1983:43).

Before people evacuate, they need to know there is a high probability a disaster will occur, that the disaster will have serious consequences, and the individual is at risk of being personally affected by the hazard (Hultaker, 1976:8). When assessing one's vulnerability to the hazard, timing is a key factor. A shorter time period "increases an individual's vigilance and propensity to evacuate" (Hultaker, 1976:9). People in this circumstance will tend to undertake fewer actions that will shift the damage curve.

Past history is another important factor in determining evacuation behavior. Hultaker argues that people tend to believe history will repeat itself. Those that have been flooded before are more likely to evacuate and to take action to reduce their damage. As noted above, the likelihood of evacuating decreases with age. Likewise women are more likely to evacuate (Yamamoto and Quarantelli, 1982:A-86) and minorities are less likely (Perry and Mushkatel, 1984:106, 215).

People are less inclined to leave their homes when they believe they will not be allowed to take their pets with them. For example, some people whose only shelter option is a mass shelter where pets are not welcome, will stay with their pet.

Quarantelli writes of another particularly troublesome problem:

> "...organizations typically have serious problems with the movement of institutionalized populations such as in hospitals, jails, nursery homes, mental hospitals...When hospitals have had to be evacuated as in the Wilkes Barre, Pennsylvania flood, or jails as in a propane threat in Everett, Washington, questions arise as to who can be released, how 'difficult' cases can be transported, where those moved can be taken, what facilities are necessary at the new relocation place, etc." (1980b:123).

Communal institutions merit special consideration when considering risk to life, health and safety. It is easy to imagine the requirements of such an evacuation would be so overwhelming as to limit the potential for damage -- reducing behavior prior to evacuation.

The literature provides considerable insight into what kinds of communities are most likely to evacuate. Planners with an intimate knowledge of their communities can use the literature to help them gauge the risk to life, health and safety in their study areas in qualitative terms. Unfortunately, there has been little research that identifies in specific terms what people do between the time they confirm a warning and evacuate.

FOCUS ON KEY ISSUES

Benefits of flood warning and preparedness systems depend on shifting damage curves. These damage curves are contours that are derived from complex, multivariate damage functions. Substantial complexity is added to the analysis by expanding the estimation of innundation reduction benefits of flood warning and preparedness systems to include not only stage but also response to flood warning. The literature is rife with accounts of the many variables that influence people's response to flood warnings. Worse yet, the results found in the literature are usually inconclusive or contradictory. Therefore, analysis of flood warning systems requires risk-based analysis.

Community differences are important in plan formulation; i.e., what is required in a preparedness system? Only those factors that are important to the analysis should be considered in plan formulation and NED benefit evaluation. The literature review is intended to point out examples of the type of factors that may be important in certain communities. Are they important in yours? The answer to that question depends entirely on the planners' judgment and knowledge of the community under study.

For example, experience is clearly a factor to be investigated. What has been the communities' response to past flood events? Almost all communities receive some kind of warning, regardless of the existence of a formal warning system. How did people respond to prior warnings? If flooding has been relatively frequent, one could expect people to be better prepared to deal with a flood threat once a warning is given. Such a community can be expected to respond in ways that cause larger shifts in the damage curve than inexperienced communities will. If there has been a history of false warnings, a community may be more inclined to wait longer before taking action, thus diminishing the damage-reducing actions taken.

Differences in response due to age may be so much esoterica for most studies. But, it's important to realize that the elderly receive warnings less frequently than others and a large elderly population risks a more significant threat to life than do other demographic groups. Is it important enough to worry about? Only specific knowledge of the community can answer that question. Planners, thus, must be aware of the multitude of factors that can affect pre-evacuation damage-reducing actions in any community. Focus only on those that are relevant to your community. If you are going to conduct surveys on a floodplain population, it may be enlightening to consider some of the factors found to be significant in prior research.

CHAPTER 4
FLOOD WARNING AND PREPAREDNESS BENEFITS

INTRODUCTION

Benefits accrue to flood warning and preparedness systems only as a result of actions taken or deferred as a result of the warning. Thus, the response of individuals and the community, as discussed above, is of critical importance. How many households will receive the message at all? How many will have enough time to confirm it and still act? What actions will they take? Will those actions be effective in reducing damages?

In the preceding chapter the rudiments of flood warning and preparedness benefits are discussed in general terms; warning systems can result in shifts in the stage-damage relationship. In this chapter, some of the more specific forms of benefits to a warning system are considered. Some of these are reflected in the shifting damage curve, others are not. Many of the examples provided are not NED benefits and are not appropriate for evaluating the economic feasibility of Federal involvement in a water resource project. They are mentioned because they may be of concern to local interests.

BENEFIT TAXONOMY

The Flood Hazard Research Center of Middlesex Polytechnic in Enfield, England has done a considerable amount of research in the area of flood warning and preparedness benefits. One focus of their early research was identifying examples of the different benefits types. Building on their work, flood warning and preparedness benefits are first classified as tangible or intangible. **Tangible benefits** can be assigned a monetary value. **Intangible benefits** cannot be assigned a monetary value, but may be otherwise quantified. This taxonomy is illustrated in Table 1.

Few extramarket effects could be assigned a monetary value a few decades ago. Now, however, it is not inconceivable in the professional literature to see monetary values assigned to the lives saved, improvements in health, and unique environmental resources. The cost of conducting such analyses may be prohibitive or the NED benefits so identified may be trivial. The techniques for valuing such consequences may be impractical for many Corps' projects but their measurement can no longer be considered impossible.

What makes a benefit "impractical" to measure in dollars is a matter of debate. While measurement may be conceivable from a theoretical perspective, it may be impossible from a practical perspective. Lack of time, budget, data, or technical training frequently render measurement of some effects impossible. Lack of professional or policy consensus on the appropriate means of measurement renders other values pragmatically impossible to measure.

Direct benefits accrue to those who put project outputs to their intended use. Direct benefits include what are commonly known as inundation reduction benefits and emergency and recovery costs

avoided. These comprise the major portion of NED benefits. **Indirect benefits** result from externalities. These may be technological externalities, such as, when flood warning and preparedness systems can be used for other disasters; or pecuniary externalities where the well-being or income of others is increased as a result of project outputs.

Benefits can be categorized as tangible or intangible and direct or indirect as shown in Table 1. The benefits described in this chapter are broadly defined. Some of the benefits described are NED benefits; others are not. Still other benefits are NED, benefits under some circumstances, but not others. Determining which benefits are NED and which are not, must often be determined on a case-by-case basis. NED benefits should be identified consistent with the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) (1983) and the National Economic Development Procedures Manual, Overview Manual for Conducting Economic Development Analysis (1991).

Table 1
Examples of Benefits Types

	Direct	Indirect
Tangible	Reduced physical Damage to flood plain occupants	Reduced time closed due to loss of flood plain markets
Intangible	Flood plain occupants lives saved	Reduced stress to family of flood plain occupants

Source: Pennington-Rowsell and Chatterton, 1979.

The following discussion is organized into the four benefit types defined by the categories of Table 1. The exclusion of an example under one benefit type does not imply it cannot be an example of another type in other circumstances. Though specific examples of benefits types must be placed in one or another of these categories, the reader is cautioned that these benefit types are more a continuum than discrete categories with precise definitions.

DIRECT TANGIBLE BENEFITS

The primary direct tangible benefit from flood warning and preparedness systems is the reduction of property damage. Techniques for evaluating these benefits are well known to analysts. Benefits can be

realized by: 1) temporarily removing property from the floodplain; 2) moving property to a safe elevation within the floodplain; 3) temporary flood-proofing; 4) opportune maintenance; 5) early alerting of emergency services; 6) orderly disruption of network systems; 7) suspension of sensitive works; and, 8) related effects on emergency costs, cleanup costs, and business losses.

The first three types have long been recognized and estimated in a number of flood damage reduction studies. The last five examples are rarely investigated and estimated in a systematic way. This may be for a variety of reasons. First, it is because these benefit types are largely dependent upon the response time available. When analysts focus on water depth and damage only, they must make some assumptions about response time that are effectively the same for the with and without project condition. In this case, there is little if any change in residual damages in these areas.

A second possibility is that analysts are unaware of the potential for such damage reductions or, more likely, the data necessary for analysis are unavailable or too expensive to gather. Third, analysts may reason that reductions in these damage categories are trivial in comparison to other benefit categories and their magnitude does not warrant the expense of estimating these effects.

Because of the modest costs of warning and response systems, investigation of these benefit types will not always be warranted in economic analyses of warning alternatives. The latter categories of benefits are going to be more likely with warning and response systems that include: 1) emergency action plans, 2) trained personnel to carry out the plan, 3) the means to foster community interest and education. Thus, if the system under consideration consists of the forecasting hardware with very little detail on the remainder of the warning process, there are likely to be few benefits from these latter categories. These require a rather sophisticated planning process and warning system. When such planning has been done, however, the benefits could be substantial.

Temporary Removal of Property

One obvious way to reduce damages is to remove damageable property from the floodplain. This alters the shape of an individual structure's depth-percent damage curve.

Automobiles can be filled with property and driven from the floodplain. In the U.S., this is the primary way of leaving an area subject to a disaster warning. Given enough time, residents can contact relatives who can provide additional vehicles for removing valuable property from the floodplain. Televisions, stereos, VCRs, and other high value but mobile equipment is easily moved from a home. Residents fearing looting can be expected to remove high value and mobile property first. Items of a personal nature, including medicines, irreplaceable photos, personal papers, etc. are also among the first items removed from the floodplain by individuals and families who have given some thought to planning for a flood.

Businesses typically have equipment, inventory and goods-in-process of much greater value than the typical home. They also have problems in moving that equipment. Relatively few businesses will have sufficient vehicles for removing their property. Rental trucks are rarely available in adequate numbers,

particularly when everyone wants them all at once. Firms may call in vehicles from other locations if there is sufficient time.

Many firms require the services of riggers and trained specialists, electricians, engineers, etc. to disassemble and move their more valuable equipment. The ability to do this depends on the size of the area in which the floodplain is located[6] and the available warning time. Some businesses, on the other hand, find significant advantages to their floodplain locations and are well prepared for floods. Inventory may stored on skids for easy removal with a forklift.

Non-profit organizations that operate as businesses have experiences similar to most businesses. Some organizations, like churches and fraternal organizations, may have difficulty competing with firms paying for scarce manpower, trucks and equipment. Neither can they rely on volunteers whose time and loyalty may be divided between protecting their home and their job.

Farmers may be able to move their livestock out of the floodplain if given enough time. Harvested crops can also be removed under some circumstances. Neal and Parker found that British farmers' ability to successfully move property from the floodplain depended on their receiving warning and being able to work during daylight hours.

A particularly important class of properties to move includes valuable papers (e.g., papers with sentimental value[7], accounts receivable, telephone lists, files), photographs, stocks, bonds, etc. Businesses inexperienced in flood recovery often protect valuable equipment first only to learn the hard way that they cannot resume their business without customer lists and accounts receivable records.

If property is stored outdoors, losses prevented must be net of any residual damage that might be incurred due to the elements during storage.[8]

Removal of property from the floodplain results in a downward shift in the stage-damage curve. The shift will not likely be a parallel shift in the curve. The nature of the shift in the damage curve will depend on the location of the removed property in the structure. If there is nothing removable at the lower elevations of the structure the without- and with-project condition damage curves may coincide at lower levels as shown in Figure 10. If the items removed are spread throughout the elevations of the structure, a shift like that shown in Figure 11 is more likely. For contrast, Figure 12 shows a case with no removable

[6]Large urban areas, for example, may have a source of available emergency labor that a smaller area may not.

[7]These may more appropriately be considered direct intangible benefits.

[8]Businesses that removed property from a Pennsylvania flood plain to an open meadow on high ground sustained substantial property damage during a storm that occurred before the flood plain could be reoccupied.

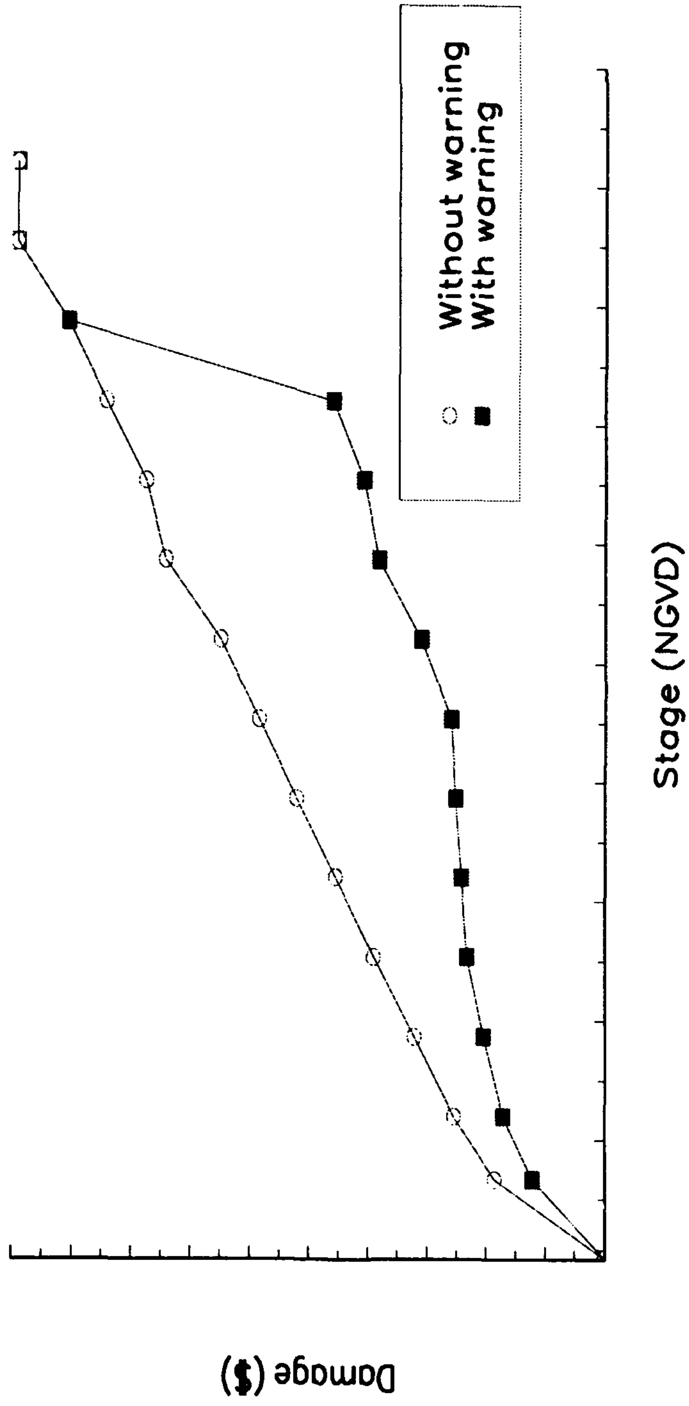

Figure 10
Moveable Items at Middle Elevations

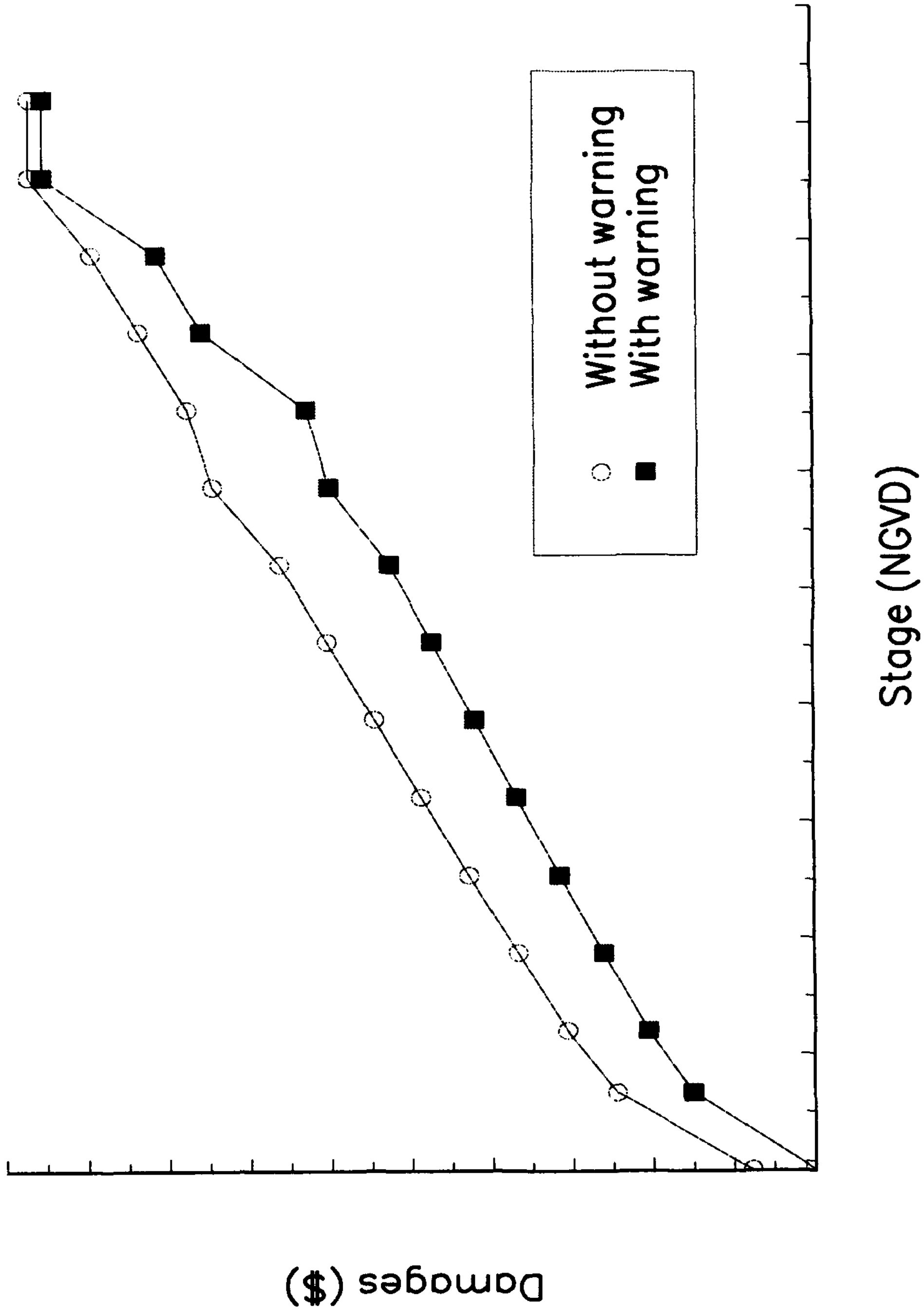

Figure 11
Moveable Items Throughout Structure

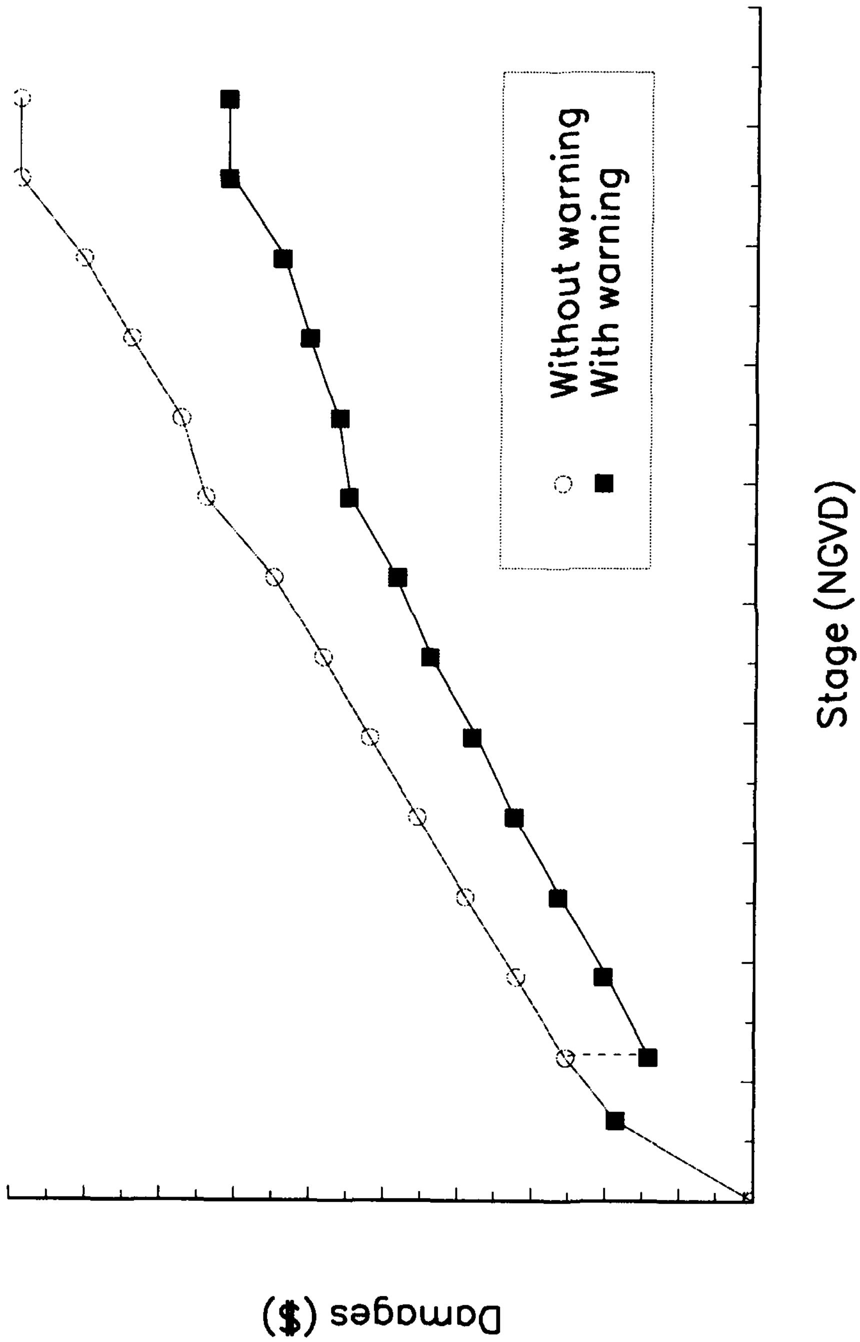

Figure 12
Moveable Items at Greater Elevations

property at lower levels and increasingly more at upper levels. Figure 13 reflects the removal of one or more items of considerable value from the structure.

Moving Property to a Safe Elevation Within the Floodplain

Residents and businesses occupying multi-story buildings may have the opportunity to protect moveable property by relocating it from basements and ground floors to higher levels. Carpets, furniture, electrical equipment and other residential property are frequently moved by residents to higher floors in their homes. Businesses may be able to use higher floors and rack storage to move property out of the reach of flood stages. For minor floods, it may be sufficient to move property to higher elevations in the same room.

Even when it is not possible to move property to higher floors in a building, property owners may be able to move goods to high ground on their property. Businesses and homes located on lots with varying topography may find that part of their land is flooded while part is not. It may be feasible to move belongings out of the reach of floodwaters without removing them from one's property.

The success of such actions depends on the accuracy of the forecast and a knowledgeable response to the forecast. During the 1972 Agnes event, the Pennsylvania owner of a fleet of cement trucks moved the trucks to high ground on his lot expecting them to be well out of the reach of floodwaters, based on the official forecast available at the time he took action. The forecast was revised as the owner drove home. Returning to his business, his access was blocked by high water. The trucks were inundated.

The success of moving property to higher elevations to avoid damages depends on the actions taken and the depth of flooding. Moving property offers limited opportunities for reducing damages in one story homes without basements during floods with great depths of water. Removing property from a basement to a first floor is effective only if the first floor is not flooded. Likewise moving property to higher floors is effective only when those floors are not flooded.

Moving property within a structure does not alter the total value of property at risk of flood damage. It does, however, alter the stage at which that damage occurs. Hence, shifts in damage curves for this type of measure will typically have the without and with project curves diverging at lower elevations, only to converge at higher elevations. Figure 14 presents an example of such a curve.

Temporary Flood-proofing

The existence of warning systems makes it sensible to undertake purchases of equipment or structural changes in one's building that will be available for use during the time of flooding. Warnings issued with sufficient lead time allow property owners to implement temporary flood-proofing activities that can reduce flood damages. These include such things as sandbagging openings and anchoring property that could be carried off by flood waters or broken loose and damaged by rising waters. Intentional flooding of basements and floors can equalize hydrostatic pressures that would otherwise damage structures and property.

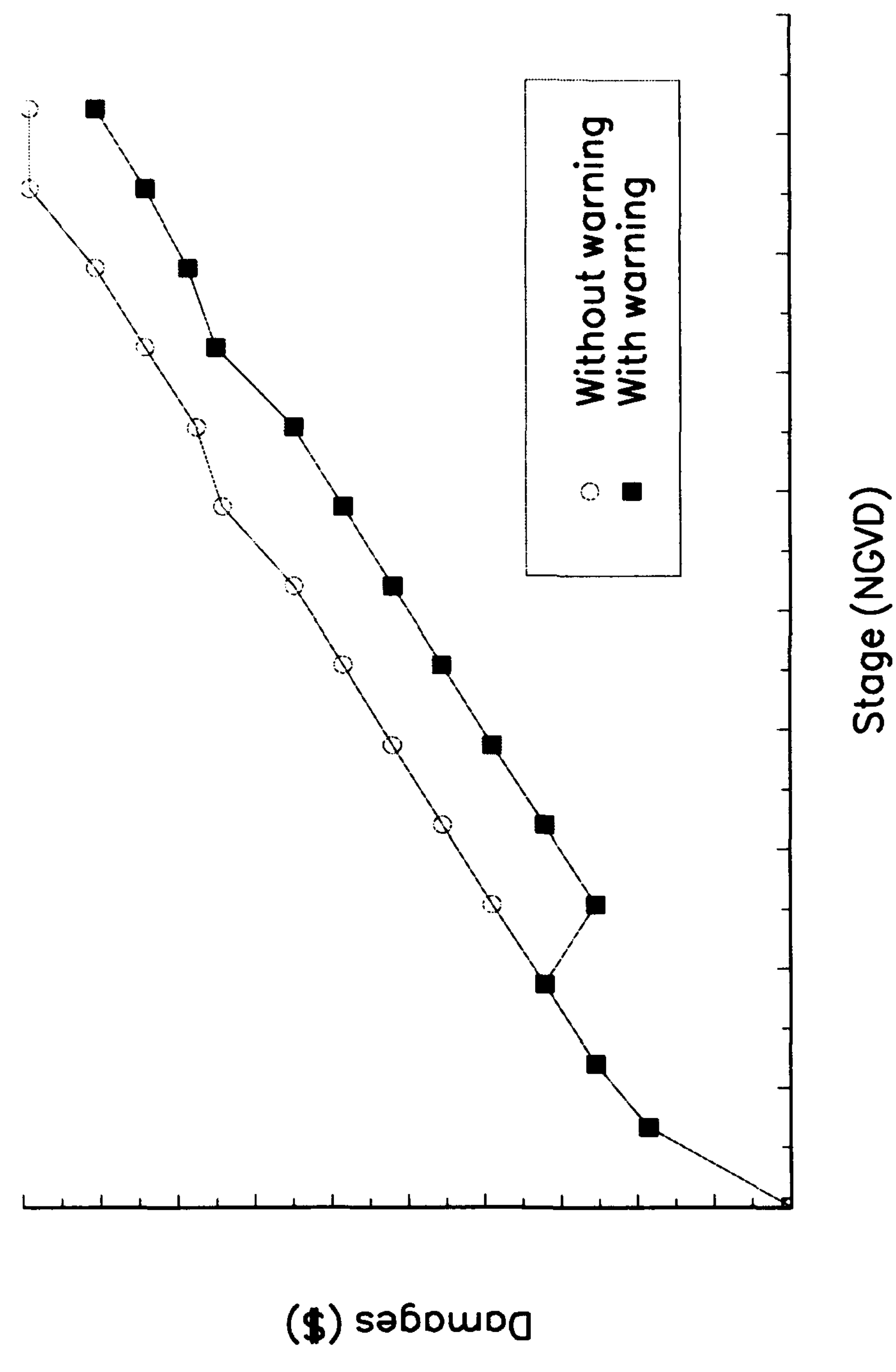

Figure 13
Items Removed from Structure

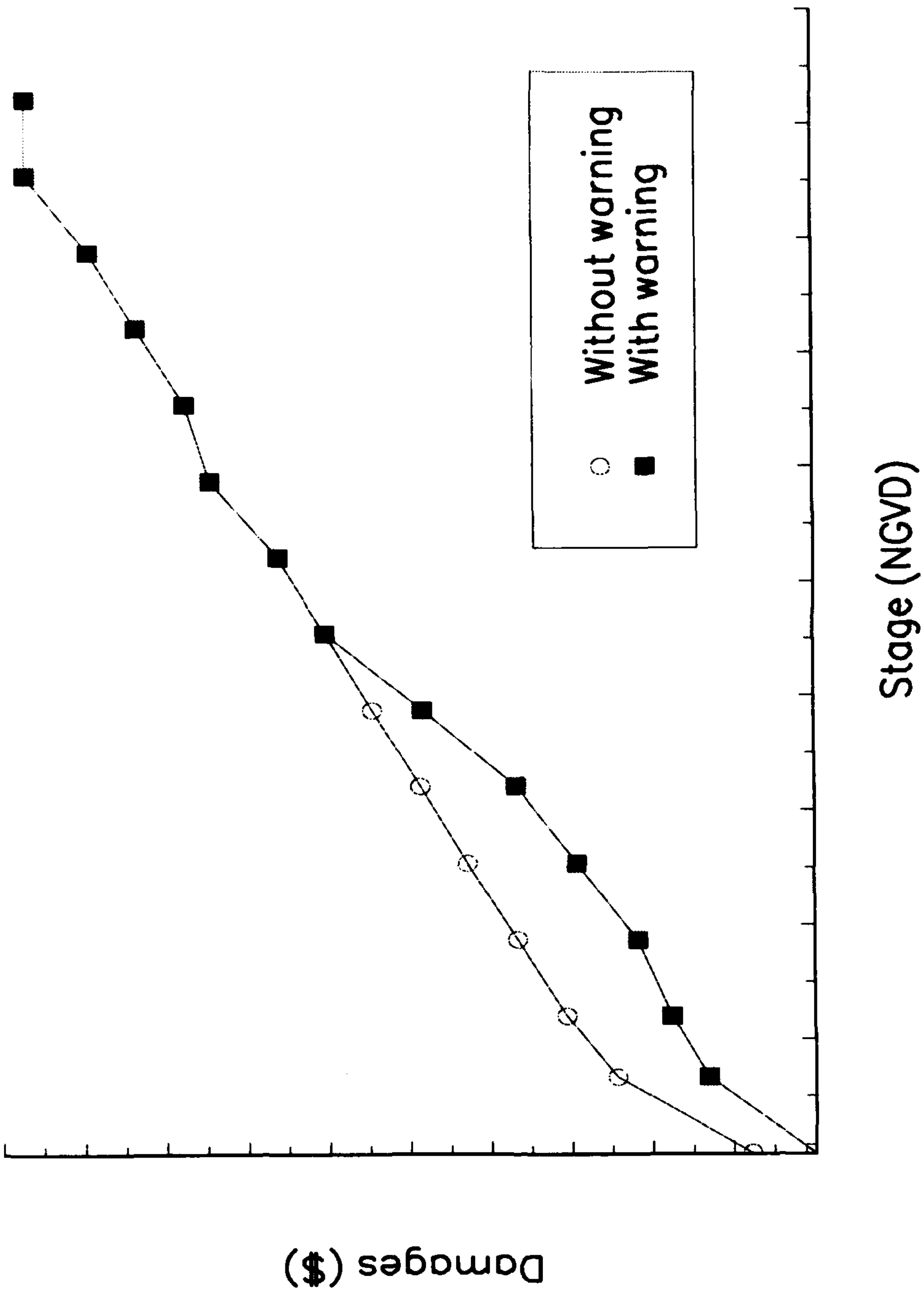

Figure 14
Property Rearranged in Structure

Given time, some property owners will be able to implement semi-permanent flood proofing measures. For example, a newspaper publisher in the Susquehanna basin installs seals over windows and doors during the time of a flood. Many businesses have found it desirable to protect in-place equipment by disconnecting electrical equipment and gas lines, and greasing or wrapping sensitive parts of their equipment.

While businesses may be expected to use these techniques in greater portions than homeowners, homeowners may also practice temporary flood-proofing. The extent of their effort may range from stuffing towels under doors to installing backflow valves and installing closure structures in ring levees. A number of residents in Georgia's Peachtree-Nancy Creek basins have decorative perimeter walls that double as ring levees when gates are replaced by closure structures. Removable utilities, such as furnaces, electric motors, etc. have also been used by some homeowners. The greatest potential for temporary flood-proofing measures to reduce damages significantly would appear to be among businesses with formal flood emergency plans.

The effects of temporary flood-proofing on a structure's damage curve can be modeled the same way a levee or floodwall project is modeled for a community. Another alternative is to model the effect as shown in Figure 14 above; it simply depends on the nature of the flood-proofing measure. A measure that flood-proofs the entire structure would be modeled as in Figure 15. A measure that flood-proofs only certain elements of the structure would be modeled as in Figure 14.

<u>Opportune Maintenance</u>

A substantial amount of damage found when floodplain occupants return to their homes and businesses after the flood waters recede is due to the indirect effects of a flood rather than to actual flood damage. For example, fires and explosions are not uncommon in floods. The damages that result from fires and explosions is not a direct flood damage; but they would never have occurred in the absence of a flood. Natural and propane gas lines rupture in homes as appliances are moved about by rising waters. Gas leaks fill rooms and structures with devastating consequences if sparks are present.

Water supplies can be contaminated and sewage spills can result if the flood stage is not anticipated in sufficient time. Wastes routinely discharged into sewage systems by businesses can end up in watercourses increasing damages to property[9] and the environment. This can be even more troublesome in communities where combined storm and sewage water systems exist. A warning and response system can provide officials and individuals with more time to undertake what is here called opportune maintenance This maintenance can be as simple as closing a shut-off valve on a gas line and halting

[9]Many businesses routinely discharge a variety of organic and inorganic materials and solutions into the sewage system. For example, a corned beef processor in one flood plain routinely discharged animal fat into the sewage system, despite the fact that it was against the law to do so. A combined sewer overflow released these fatty wastes in the vicinity of a machine shop where they contributed greatly to the damages caused to the property there.

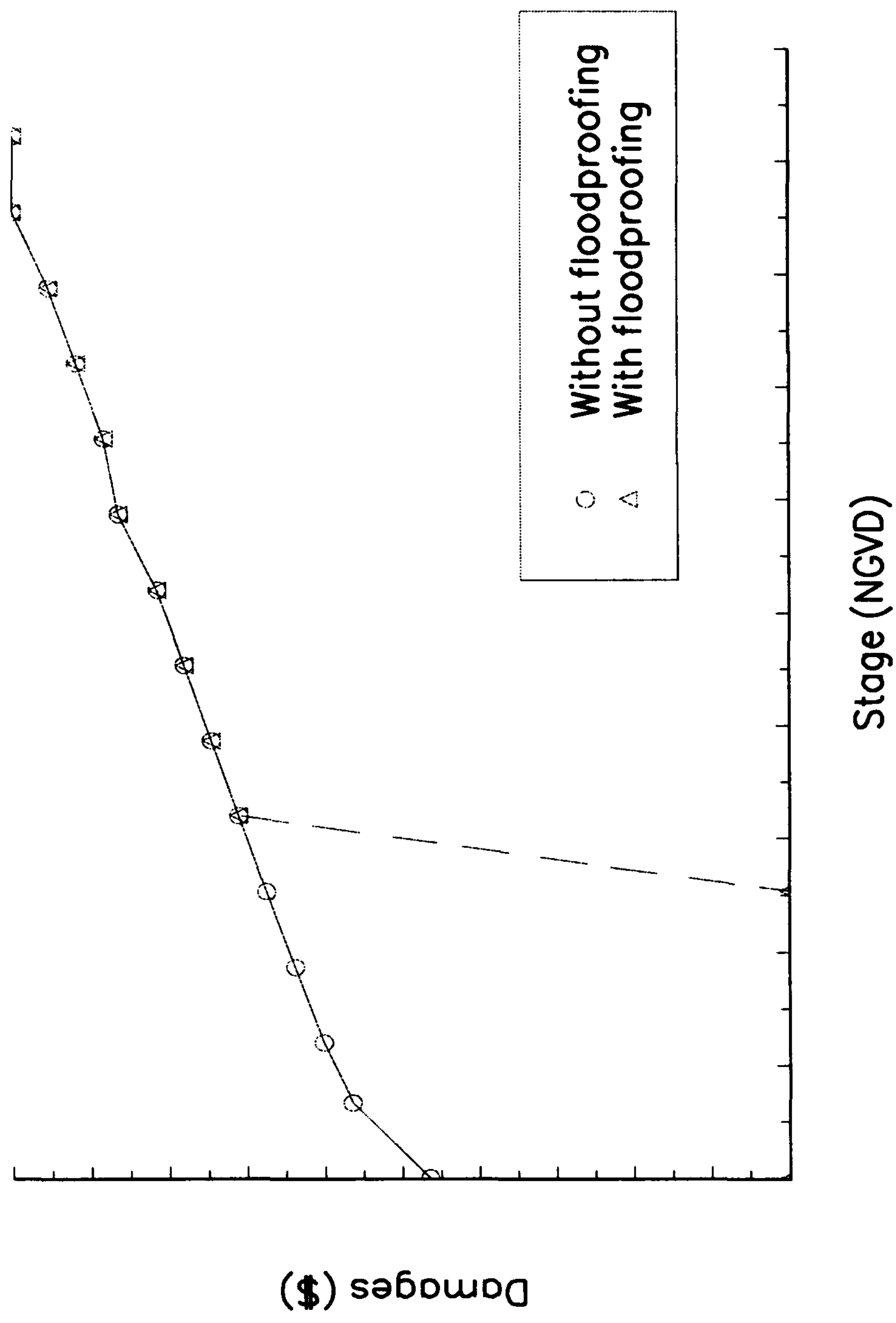

Figure 15
Floodproofing a Structure

discharge of certain materials into the sewage system, or complex safeguarding of water supplies and sewage treatment plants.

The major difficulty with estimating these NED damages/benefits is that they are difficult to measure because they are risk-based events. Fires, entry of toxic materials into the watercourse, etc., may or may not occur. For pragmatic reasons, these may not be estimated in either the with or without project condition for a flood. Nonetheless, they may, in some circumstances, be important NED effects of a warning system with significant value to floodplain occupants.

Opportune maintenance benefits can be modeled by downward shifts in the expected stage-damage curve (assuming a risk-based probabilistic approach to the analysis), provided the without condition expected stage-damage curve included these damages.

Early Alerting of Emergency Services

A major hidden cost of flooding is nature's element of surprise. Hundreds of people converging on the local high school gymnasium that is still locked and set up for last night's basketball game are minor inconveniences in the scheme of things but a one hour wait for 200 people costs society 200 hours. The opportunity cost of this time is an NED cost; estimating it may be impractical. Contacting and calling in all available emergency personnel also takes time, time during which lives can hang in the balance. Volunteers can be mobilized to save lives, minimize damages and ease the transition to recovery, given sufficient warning.

Lack of access to emergency supplies and provisions can also result in increased costs to a community. Stockpiled sandbags are no good unless they are ready for use at the place they will be needed. Four wheel drive vehicles, boats, two-way radios, etc. are often in short supply during disasters. It takes time to arrange for such resources. Mass shelters will need emergency water, food, clothing, medicine, blankets, cots, telephones, etc. for the people descending upon them.

Increased warning time can reduce the costs of emergency shelter and emergency care as individuals have more time to arrange to stay with relatives, friends, or elsewhere. Public assistance and long-term emergency shelter for evacuees could be reduced if they have time to secure/prepare their property before evacuation. Emergency expenses saved by the public sector may be financial savings without any reduction in economic costs if individuals incur personal costs equal to the public sector's savings. Hence, these benefits are likely to be transfers and not NED in nature.

Communities faced with limited personnel and other resources can benefit greatly from additional time to ready these and other emergency services. Deployment of personnel and equipment to assure medical, fire, police and other services are continued and available to all parts of the community is a service so invaluable that it probably should be considered an intangible benefit. Costs of delays in alerting and deploying emergency services are rarely estimated in flood damage reduction analyses, thus reductions in these costs have not often been quantified.

Warning makes it possible to avoid costs associated with unnecessary mobilization of manpower and other emergency actions. A preparedness plan can identify necessary resource deployments that can avoid knee-jerk over-reaction that often comes from a misdirected desire to do something or to help out.

Early alerting of emergency services can be modeled by downward shifts in the stage-damage curve, provided the without condition damage curve included these damages.

Orderly Disruption of Network Systems

Phone systems, utilities, pipelines, cable TV services, transportation patterns and traffic levels, local area networks (i.e., computer network systems) and other network systems that unexpectedly "go down" can do so in ways that affect an area much broader than the floodplain or in ways that are much more difficult to bring back up. Warning and response systems offer opportunities for these network systems to prepare for disruptions in a more orderly and, ultimately, cost-effective manner. More alternatives to continue network services can be investigated, considered and implemented if more time is available.

For example, businesses with large and dynamic data bases may routinely back-up their systems once or more a day. However, if a flood disrupts the systems operation at an inopportune time the costs to the business can be overwhelming.

This benefit type presents an area in which the analyst must know the floodplain and look for potential disruptions to networks. One key is in defining a network. Though a number of examples of networks have been identified above, networks may also be found in less obvious places. Publishing a newspaper, for example, may be likened to a network. In the aftermath of the 1972 Agnes event, one newspaper publisher was eventually able to make arrangements to have several small, independent printers publish the paper until it could reoccupy its premises. In some cases, it may be possible for businesses to make alternative plans for thier network services if they have sufficient warning time.

Rival businesses have, at times, been found to be surprisingly supportive of their competitors during times of natural disasters. The Agnes experience in Pennsylvania during 1972 yields numerous examples of businesses helping their competitors to meet their commitments and obligations while temporarily dislocated. There may be instances where a business could make arrangements to avoid or minimize disruption to network services if they have sufficient warning prior to flooding.

Orderly disruptions to network services can be modeled by downward shifts in the stage-damage curve, provided the without condition damage curve included these damages.

Suspension of Sensitive Works

Closely related to the two previous benefit types is the suspension of sensitive works. Many production processes take days to complete. For example, at least one method of producing vinegar is a continuous process that takes a week to complete. The vinegar is always somewhere inside the series of vats and pipes that make up the production equipment. While some product is finishing the process, raw materials are being fed into the beginning of the production line.

Given sufficient warning of an event that could destroy an entire batch of product, the vinegar can be stored in homogenous batches that will save goods-in-process and speed up the process of getting back into production. There are many industries with similarly sensitive processes that could be suspended with sufficient warning to allow protection of goods-in-process.

A number of production processes involve the use/production of hazardous materials. Warning systems may provide opportunities to suspend production processes to minimize the possibility of hazardous materials entering the waterway.

In addition to readily predictable effects like that above, chance will provide opportunities for other sensitive processes to be suspended. For example, consider something as mundane as the repair of a water main. Given sufficient warning, repair crews could suspend their repair work in a way that minimizes disruption to the utility. This could be by temporarily capping a pipe, shoring up an excavation, etc.

The suspension of sensitive processes can be modeled by downward shifts in the stage-damage curve, provided the without condition damage curve included these damages.

Related Effects on Emergency Costs, Cleanup Costs and Business Losses

The emphasis in the above discussion of direct tangible benefits has been on physical damages. It should be noted that any or all of the above benefit types could have an effect on emergency and cleanup costs as well as business losses. For example, a more orderly response to a flood can result in a reduced need for overtime payments of employees in flood fighting and clean-up activities. If these economic costs of operating from a floodplain location can be eliminated, they are NED benefits. Business losses, defined as total revenue generated by the sale of a product less the economic costs of generating that product, may be NED benefits. Losses that are not merely postponed to another time, or transferred to another geographic location, represent real decreases in national product and are NED benefits if prevented.

Many of the actions described above will result in a faster and less expensive return to normalcy during the post-flood period. Reduced unemployment and income loss, smaller losses in sales (and, consequently net income), and smaller reductions in taxes collected can result from a quick recovery. These losses are usually regional transfers and are not NED effects. Costs for flood insurance could be reduced as warnings result in decreases in the amount of coverage required by residents and businesses.

These costs and losses can be modeled by downward shifts in the stage-damage curve, provided the without condition damage curve included these damages.

Traffic Control

Implementing appropriate traffic controls takes time. Forecasts provide the opportunity for authorities to decide which roads to close and which to keep open before flooding begins. Traffic can be re-routed in a more efficient manner and personnel can be deployed in a timely manner to block access to potentially dangerous areas as well as to direct traffic on detour routes, etc. The value of the time saved and the avoidance of increased economic costs of transportation through such efforts can be NED benefits.

DIRECT INTANGIBLE BENEFITS

Many of the effects of a warning system accrue directly to the residents and users of the floodplain, but they cannot be readily measured in monetary terms. In an effort to categorize some of these effects, a number of benefit types are described below. There is considerable overlap among some of the categories. The distinctions and examples of benefit types that follow are offered merely to suggest some potential benefits. Experienced planners will be able to expand on these examples.

Human Health and Safety

Flood warning and preparedness systems can result in the timely and orderly evacuation of a floodplain. Evacuation of a floodplain prior to flooding reduces risks to evacuees. As people are removed from the hazard area they are personally immune to its dangers. Warning time is especially necessary for the evacuation of institutionalized populations in hospitals, nursing homes, schools, prisons, etc. Likewise, timely warnings protect volunteers and emergency personnel by minimizing the need for them to conduct rescues.

The provision of early alerts furnishes opportunities to arrange needed assistance for individuals who are invalids, handicapped, or that need more than the normal amount of time to evacuate. Warning systems provide additional opportunity to make and implement decisions about closing schools and places of employment to minimize persons exposure to danger. Action can be taken to prevent travel into hazardous areas.

In addition to providing substantial threat to the health and safety of floodplain occupants, floods produce a risk of injury or death to patrons, students, patients, inmates, visitors, and employees of public and private facilities. Though questions of liability for such injury or death are beyond the scope of this report[10], warnings can contribute to a significant lessening of whatever liability may exist.

Public health problems in the post-flood period can be minimized if there is sufficient warning time to undertake opportune maintenance, suspend sensitive works, and provide for an orderly disruption of network services. Equipment and materials necessary for basic health and hygiene needs are more readily available when and where needed, if they are readied and deployed prior to the flooding rather than during or after. For example, vaccinations against disease can be more effective if available before the onset of a problem.

Safety can be better assured if there is sufficient time to evacuate everyone, especially those requiring extra time to evacuate; and if access to dangerous areas can be controlled at the earliest opportunity.

[10]The 1989 study by Neal and Parker (p.52) points out that the legal position over responsibility to provide flood warnings is still evolving. Their opinion is that the obligation to provide flood warnings may be stronger than previously believed based on common law developments in Australia.

Use of System for Other Disasters

Flood warning and preparedness programs can serve a number of purposes. Significantly, they can serve as the core around which other disaster preparedness plans can be organized. Communities vary in the range of disasters they face; earthquake, storms, fire, hazardous materials accidents, etc. are among the possibilities. A warning system helps to put in place the process for dealing with these emergencies. Lines of communication are established, warning dissemination patterns exist, etc. To the extent that education or experience spawn a disaster subculture in a community, it will be better prepared to deal with any emergency. Thus, a flood warning system could contribute indirectly to the protection of lives and the enhancement of health and safety during other disasters.

Cost of Employment Disruption

Many of the costs of employment disruption are direct and tangible. Lost productivity is an NED cost. Lost income is of paramount concern to the individual. As income is lost, tax revenues are decreased. If production and income are made up at a later time or another place they are not NED costs.

The decline in tax revenues is accompanied by a rise in public expenditures making a balanced budget more elusive. The public sector bears some share of the costs of recovery from the flood and is faced with increasing demands for public assistance as individuals lose their means of support, further straining the public sector's finances.

Warning systems provide time that allows firms to suspend business and prepare for the flood in a manner that will minimize the time and expense of getting back to business after the flood. Less well known are the intangible effects of unemployment. Even if an individual or family survives the flood they may not survive the unemployment that results. Unemployment has been shown to cause an increase in crime, suicide, spouse and child abuse, and substance abuse of all kinds; increases in mental breakdowns, stress-related illnesses, and inattention to health problems (often due to loss of health insurance). To the extent that flooding limits unemployment, it simultaneously limits the extent of all these problems as well.

Reduced Stress

Loss of life and injury can cause incredible stress to the family of the victim and to the injured victim. Reducing the number of these events through warnings will lessen flood-related stress. Not all of the stress-inducing events need be as serious as death and injury. It is a way of life for some floodplain occupants to cancel outings, trips and vacations because of weather that has produced flood conditions in the past. Many occupants claim they cannot be away from home for fear of flood damages. Others can't sleep when it rains heavy.

The presence of flood warning systems in England has resulted in considerable "customer satisfaction" (Neal and Parker). The mere presence of a warning system provides many floodplain occupants with the reassurance that if there is a need to worry, someone will tell them to worry. Thus, the warning program eliminates a lot of unnecessary worry.

Family Disruption

One form of stress is so common and so debilitating that it deserves to be separated from the other stress issues. Disruption of the family unit is a common consequence of some types of flooding. It is common for a family to be widely dispersed during the course of a normal day; parents at separate workplaces, children at one or more schools or day care facilities, an aging grandparent at home. When a flood is imminent or occurs, the family's energy is often channeled into reuniting at any cost. With roads blocked, communications down and water rising, the stress can become unbearable, often producing irrational behavior.

A warning system can be expected to provide authorities with the time they need to make better decisions about closing schools and other facilities. Families will have more time to reunite and verify the safety of other family members, thus reducing stress significantly.

Loss of Memorabilia

Most property losses are readily accounted for through traditional estimation of changes in expected annual damages without and with the warning program. Traditional methods of valuing property may be inadequate for that class of property called memorabilia. The beat-up and scratched old table by the door may have negligible value to an antique collector but it may be invaluable to the owner because it has been in the family for generations. Wedding albums, photographs of first haircuts and the like are essentially worthless to people outside the household; but they are a family's history and are irreplaceable to a few.

Forecasts and warnings can provide the time and instruction necessary for people to gather and remove those most prized possessions.

INDIRECT TANGIBLE BENEFITS

Every direct tangible benefit described above can produce similar indirect tangible benefits (e.g., planned and careful disruption of network services can benefit floodplain occupants and others). This discussion of indirect tangible benefits is separated into production and consumption externalities roughly according to whether they involve the non-residential or residential populations of the community.

Production Externalities

A major producer of canned foods is located in the floodplain of the Susquehanna River. A few miles away, well out of the floodplain is a small manufacturer of steel cans. Over ninety percent of their product is sold to the floodplain firm. When a flood halts production at the cannery, it indirectly halts production at the can manufacturer's as well. A warning system that limits the impact of a flood on the cannery limits the impact of the flood on the manufacturer. These impacts could include NED benefits if the lost production is not deferred in time or transferred in space.

The production relationships in our economy are complex and varied. Firms far from the floodplain may have their fate tied to the fates of floodplain firms or services. They may depend on

floodplain firms to provide their inputs or to buy their products. They may rely on travel, communication or other network linkages with the floodplain or located in the floodplain. When there are physical or economic ties between floodplain and non-floodplain firms and activities, direct tangible benefits to floodplain firms and activities are likely to be accompanied by indirect tangible benefits to non-floodplain firms. The significance of these effects can only be determined on a case-by-case basis.

Consumption Externalities

Repeated flooding can degrade property and cause reductions in property values that are either short-term (in the immediate aftermath of a flood) or long-term (more or less permanent) in duration. The value of adjacent non-floodplain property can be likewise diminished by its proximity to low value properties. These effects can also lead to consequent reductions in tax revenues for the community. Warnings that allow property owners to mitigate the effects of floods on their property may also have the effect of allowing the real property to better hold its value. This is a benefit to the floodplain property owner, adjacent property owners, and local tax authorities but it is almost certainly a regional or local benefit, not an NED benefit.

Residents of non-floodplain properties can realize positive externalities from a warning and response program. Many people may be dependent upon floodplain activities for their jobs. A warning system could get an employee of a floodplain firm back to work sooner; or, an employee of the can manufacturer may avoid a lay-off because of the system. Consumers who shop, study, recreate in or otherwise use the floodplain will also benefit from a more rapid recovery from flooding.

INDIRECT INTANGIBLE BENEFITS

Reduced Stress

It is not just the occupants of floodplains who suffer stress-related maladies as a result of flooding. The families and friends of floodplain occupants are affected by the death and injuries of loved ones. Even when no harm occurs, the mental health of families and friends can suffer tremendously as word of a flood arrives and it is impossible to establish contact with the floodplain occupant. Catastrophic events can affect the mental health of an entire community.

Warning and response programs can mitigate the stress of non-floodplain occupants by reducing death and injury. The orderly disruption of communication networks could contribute to less time between news of a disaster and the reassuring contact from a loved one.

Flood warning and preparedness COSTS

The costs of flood warning and preparedness systems have been well documented in both the literature and in project reports. Davis and Burnham (1986:15) provide a concise summary of flood warning and preparedness costs that is modified and reproduced in Table 2. A 1990 Report for IWR, "Procedures for Calculating the Costs and Benefits of Flood Warning and Preparedness Systems," provides

Table 2
Potential Cost Items:
Flood Warning-Emergency Preparedness Plan

First Costs

- Development of plans
- Outfitting/equipping administrative facilities
- Purchase/installation of equipment and hardware
- Development/printing brochures and instructions
- Stockpiling equipment and materials

Annual Periodic Costs

- Updating flood recognition methods and formal warning, response, recovery, and continuous management plans
- Updating/pringing brochures, instructions, etc.
- Operation drills
- Supplement/replace stockpiled materials
- Equipment/hardware operations, maintenance and replacement

Event Costs

- Personnel overtime and emergency hiring
- Equipment purchase and rental
- Transportation/storage of personnel property
- Materials supplied/consumed
- Mass care operations
- False warning

(Davis and Burnham, 1986)

a detailed description of system first costs as well as operation and maintenance costs. These costs are not considered further here.

Flood warning and preparedness systems can impose hidden costs on a community. For example, the Colorado experience detailed by Worth and McLuckie indicated that successful and well-publicized mass media warnings had the undesirable side effect of attracting large crowds of "curiosity seekers" or "gawkers" to the disaster site. These crowds present crowd-control/access problems that divert scarce resources from disaster response to crowd control activities. The opportunity cost of these diverted resources can be very high in some cases. In some cases the curiosity seekers have foolishly placed their own lives and safety in jeopardy, creating a new population of people at risk of losing their lives and endangering volunteers and emergency personnel assigned to dispatch them.

Perhaps the most important hidden cost of a successful warning system is the cost to the individual of additional time for responding to the warning. Each response action undertaken by a resident or business person has an opportunity cost. Warning systems are assumed to provide additional time for individuals to respond to the impending flood. Actions taken during that additional time can be costly. For example, with sufficient lead time individuals may opt to take leave from work in order to reduce the damages to their home.

To the extent that the productivity of workers who take off in this fashion cannot be recaptured, this represents NED cost.

The costs of removing property from the flood's path can be substantial. And, to the extent a warning system causes an increase in these costs, they must be considered part of the system's costs. These costs include wages, the value of personal or volunteer time and the opportunity costs of the vehicles and other special equipment used.

Implicit costs can include the value of time spent moving property, protecting it from vandalism, etc. One hidden cost of removing property that must be considered is the cost of storage. If a flood lasts any length of time or if reoccupation of the floodplain is delayed for any reason, property owners must find a place to store their property. This storage may have explicit costs, such as will be incurred when storage space is rented; or implicit costs, as may be incurred when relatives give up the convenience of the use of a garage.

Unsuccessful efforts to move property out of the reach of flood waters can actually increase the damage incurred during a flood. The opportunity cost of a family's time and materials expended in a flood fighting effort may be a significant addition to the physical damages they sustain when floodwaters extend their reach beyond the expectations of the family's flood fighting efforts.

Efforts to move property to higher ground have costs as well. Explicit costs include any expenditures for equipment or labor, etc. Implicit costs include the value of time spent in moving items. Increased risk of injury and heart attack induced by strenuous and stressful efforts to relocate property may be significant in communities with elderly populations.

Successful evacuations also impose costs on society. Evacuees typically stay with relatives, friends, motels/hotels, or mass shelters. Costs imposed upon friends and relatives may be substantial but as a practical matter they are ignored, despite the fact they may be NED costs. Costs of motels are easily estimated, but frequently overlooked. Mass shelters can be costly to operate in both financial and economic terms because these shelters frequently have important alternative uses. As with the estimation of benefits, these costs should be compared for with and without project scenarios.

Perimeter control of a warned area can be very expensive. Security is provided by people who typically do not know the residents. This can impose hardship and delay on people with a legitimate right to reenter their communities.

A final cost to consider is the cost of a false warning. Decision makers face a sometimes difficult trade-off (addressed in some detail by Haimes, Krzystofowicz, and Li: 1990) between accuracy of forecasts and the probability of false warnings. False warnings can be costly because they entail substantial costs of mobilization of emergency personnel and resources as well as costly private responses to the warning. False warnings are an inevitable risk with any warning system and they must be evaluated.

False warnings can be avoided by holding back on the issuance of a warning until flooding is certain. The cost of this delay is to diminish the amount of response time available. In extreme situations, there may be no response time left. At the opposite extreme, warnings could be issued with every heavy rainfall, resulting in frequent false warnings and a "cry wolf" syndrome. Every evaluation of a flood warning and preparedness system should consider the costs of this trade-off between response time/system benefits and the costs of false warnings to the extent warranted by the study's circumstances.

CHAPTER 5 FLOOD FORECAST AND WARNING BENEFIT EVALUATION MODEL

INTRODUCTION

A benefit-cost analysis should be performed for every flood warning and preparedness system considered for implementation by a Federal agency. In these cases, NED is the proper accounting perspective for identifying benefits and costs. Benefit-cost analysis should be performed for any systems under consideration by non-Federal interests where the resources of the sponsor of the system are limited. In these cases, it may be appropriate to consider regional or local benefits and costs which may differ substantially from NED effects.

Evaluating a flood warning system is a complex problem. Neal and Parker investigated a number of alternative evaluation techniques; each with a different performance indicator. First, they considered the proportion of flood prone properties within a region served by a flood warning service. Identifying the number of properties served is amenable to average cost computations and saturation of coverage comparisons.

Flood loss reductions was the second indicator considered. The third alternative is to measure customer satisfaction with the system. In a round of surveys, they tried to determine the level of customer satisfaction of flood warning recipients with the warning they received. This measure has become controversial, however, because though it can be foolish and self-defeating to ignore the views of one's customer base, in this case, the customers have neither the technical expertise nor the intuitive basis for offering truly valuable commentary on the system's performance.

A fourth indicator proposed is to identify, categorize and record flood warning failures and to compare these failures to system successes, for the purpose of improving the service. The fifth indicator is a count of the number of flood victims who receive an official flood warning within a given time before flooding of their property begins. This number could, perhaps, be compared to the number of people covered by a warning system. The sixth indicator was a pure performance measure; compare the forecast (say timing and depth) with what actually happened.

While each of these six indicators has its utility and proponents the seventh indicator considered by the authors is the one used by the Corps of Engineers. It is a full benefit-cost analysis. The difficulty with this indicator is that flood warning and preparedness system evaluations can be conducted at a variety of levels of planning.

Continuing authority programs, planning assistance to states, floodplain management services, reconnaissance studies, feasibility studies, reformulation studies, and special investigations are some of the planning settings in which warning and response programs might be evaluated. Each setting has different data, time, budget, and personnel constraints. The level of detail appropriate for a feasibility study is

simply not possible in other settings. The analysis that suffices for a $25,000 warning and response system would be woefully inadequate for a feasibility study.

Though the requirement for a benefit-cost analysis may be the same for all planning settings, the level of detail required and the sophistication possible run the gamut from negligible to appreciable. In this chapter, a model that can be adapted for use to many planning settings is presented. It is a simple expected annual damage computation model created in a spreadsheet environment using Lotus 123 and @RISK, a Lotus add-in software product.[11] The model can be used at different, broad levels of detail. Three levels are presented here. The simplest application of the model requires nothing more than a stage-damage curve, some basic assumptions, and the model presented here.

The model is an after-the-fact application of the model using existing data. The most sophisticated application of the model requires the careful collection of structure-specific data as illustrated in Figures 10 through 14, a stage-damage compilation program like the Hydrologic Engineering Center's Structural Inventory for Damages and Expected Annual Damages programs or their equivalent, and the model presented here or its equivalent. It is a before-the-fact application of the model. Between these two extremes is a middle ground application of the model, that can be used before, during, or after the collection of stage-damage data.

Development of the model begins with a discussion of the state of existing warning systems in the without project condition. The basics of the model are then presented. After the initial presentation of the model a simple application is presented, followed by a number of more complex applications with accompanying explanations. The applications are numbered for ease of reference.

Data were obtained from a Corps' project for use in most applications. The data are from a large and densely developed urban area. Hence, the magnitudes of EADs and benefits are likely to be much larger than the benefits obtained in most project areas where flood warning and preparedness systems are being considered. It should be clear that the bulk of damage reductions that result from warning systems will accrue to the contents of structures rather than the structures themselves.[12] Though the stage-damage curve used includes all types of damages for simplicity, it is treated as if it is content damage only. The results and applicability of the model are not affected by this fact.

Two basic models are presented. The first is the benefit model; the second is called the "Response Model" and it is described in a later section. Chapter 5 presents some empirical results found in the literature that could be of use in using both of these models.

[11]Lotus 123 is available from the Lotus Development Corporation, 55 Cambridge Parkway, Cambridge, MA 02142. @RISK is available from Palisade Corporation, 2189 Elmira Rd., Newfield, NY 14867.

[12]Though flood-proofing, opportune maintenance and other benefit types described in the previous chapter may result in reductions in structural damages, we will not make distinctions in the nature of the damage reductions and will effectively assume all damage reductions are to content damages.

WITHOUT PROJECT CONDITION WARNING ASSUMPTIONS

There is no such thing as a flood prone community that has no flood warning and preparedness system. It may be informal and unsophisticated, ranging from aching joints to watching the river rise. The dissemination of the message may be limited to police driving through with a bullhorn, neighbors calling each other, or to asking everyone why they're leaving an area in a such a hurry. The point is, any without project condition includes some level of damage reducing activity that people already undertake. This activity should be reflected in the without project condition stage-damage curve.

Damage estimates prepared from interviews can easily account for flood fighting activities that would reduce damages. Normal flood fighting activities are readily determined during an interview. Damage estimates obtained from standardized curves, however, are a different matter. Curves based on empirical damages, i.e. Flood Insurance Administration (FIA) curves, already reflect reductions in damages due to the actions of individuals. Whether the damage reductions reflected in these curves, generalized from data over a wide geographic area, are representative of the study area is a problem the analyst should consider in unique areas.

The general applicability of curves standardized from a large area to any one specific area raises issues of more importance than the representativeness of the damage-reducing behavior imbedded in them. This latter issue is rarely addressed in practice because the difference in damage-reducing behavior among regions of the country is likely to be trivial. Using these standardized curves, estimates of warning system benefits are as likely to be a little too high as a little too low. In the absence of any consistent bias, however small, there appears to be no reason to worry about this difference.

In some studies, District personnel develop stage-damage curves specifically for the study area. These curves are usually constructed in one of two general ways. First, they may be empirical, i.e., based on actual damages that resulted from past floods. Such curves are likely to include the damage-reducing activities that result from the existing warning system. Curves generated in this manner will likely yield the truest estimates of flood warning and preparedness system benefits.

The second approach is to survey homes, noting the value and elevation of property within the home. Depth-percent damage curves are then generated from this information, based on susceptibility of structures and contents to flood damages. Surveys such as these do not necessarily reflect damage reducing activities of floodplain occupants unless these activities are expressly explored during the data collecting surveys. Benefit estimates prepared from these curves are likely to be biased in the direction of over-estimating benefits because the without project condition expected annual damages are overstated if damage reducing activities are not explicitly considered.

CURRENT METHODS

Shifting the Damage Curve

Corps Districts primarily use one of two methods to estimate warning system benefits. One is to effect a parallel shift in the stage-damage curve to reduce the amount of damages at every stage of flooding.

These shifts are normally a one- or two-foot shift in the stage damage curve. This method is illustrated later in this chapter.

The Day Curve

The most common method of modeling the benefits of a warning system is through use of modified Day curves. Harold Day, in a series of publications, developed a method that introduced the consideration of warning time to the stage-damage relationship. The basis for the original work was an early 1960s synthetic data base built by the Baltimore District based on information obtained in the Susquehanna River Basin for the development of the District's Damage Assessment Program (DAPROG). Baltimore personnel developed detailed estimates of flood damages for varying depths of water to different classes of residential property types classified by size, number of stories, class (a condition variable), basement, and a subjective measurement of the value of the structure's contents. For each structure type, a depth of water-dollar damage relationship was expressed. These individual structure curves were not depth-percent damage curves; they were depth-dollar damage curves. Damages were expressed in 1963 price levels.

The curves were constructed from detailed data about the contents, their value and susceptibility to damage. For example, from file data it was possible to identify the precise dollar damage assumed to be incurred by a television set with two feet of water on the first floor of a house. Using this rich detail, Day used these detailed data to make judgments about what items could be removed from the path of flood waters. By re-adding the content damage, he obtained a new depth-dollar damage curve for each structure type. These damage reductions were standardized by converting them from dollar reductions to percentage reductions.

Day performed this tedious work for three basic warning scenarios: maximum practical evacuation, limited warning time, and limited response to warning time. Thus, Day identified a shift in the damage curve for each of these warning scenarios. This is conceptually consistent with the presentation of Chapter 2.

Over time, these curves have been produced and reproduced showing the damage reduction as a percentage of without project condition damages that occurs with varying amounts of response time. The Day curve methodology is perfectly applicable today. The actual Day curves, however, should not be used. The Day curve methodology was surely a pathfinding work at the time, but continued use of curves based on the contents of a typical house in the early 1960s likely do not apply to current floodplain situations. There is nothing inherently wrong with the Day curve approach to estimating warning system benefits. The model presented in this report simply builds upon it. There is, however, no rational justification to continue to use the actual curves developed by Day.

MODEL OVERVIEW

A risk-based model has been developed to estimate flood warning and preparedness benefits in a spreadsheet environment. Figure 16 displays the basic workings of the model. Without project condition

EAD are calculated as usual. With project condition EAD are calculated for as many response scenarios as the analyst cares to identify.

A warning time is randomly generated from a distribution of warning times specified by the analyst. The generated warning time serves as a filter, allowing only the response scenario that includes the warning time to be considered further. This one and only response scenario, i.e., the with project condition response scenario that includes the randomly generated warning time, is the one used to estimate benefits. The with project EAD that pass through this "warning time filter" are subtracted from without project EAD to obtain an estimate of benefits. The calculation is repeated as many times as desired. A distribution of project benefits is obtained and the mean of this distribution is the estimate of project benefits. The values of any variable or relationship used in the model can be varied or saved in an output file for future analysis.

Each of the major steps in the functioning of the flood warning and preparedness benefit model is discussed below:

Warning Time

The amount of warning time provided by a flood warning and preparedness system will vary from project-to-project as discussed in Chapter 2. It will vary with the characteristics of each flood event, the natural characteristics of the basin, the social characteristics of the community, and the technical characteristics of the system itself. Small basins with steep terrain will yield less warning time than very large basins with mild slopes. Widely dispersed rural populations may have less time to respond than populations in dense urban areas with multiple opportunities for disseminating warning messages. Systems that rely on visual inspections of precipitation or stream gages will not generally provide as much warning time as more sophisticated systems with automatic reporting of rainfall and streamflow information.

The analyst will always have some information about the warning time available. The amount of warning time might be identified in a number of ways, for example an average warning time, a minimum and maximum warning time, a minimum, maximum, and most likely warning time, a mean warning time and standard deviation, etc. At the same time, the analyst will never know precisely how much warning time will be available for any one event. Some range of possible warning times can always be identified. Some warning times within the range of possibilities will be more likely than others. Any range of values, with some probability of the values in that range occurring, can be described as a probability distribution.

In the hypothetical application of this model, the warning system is assumed to provide from 1 (a minimum) to 24 (a maximum) hours of warning. Such a range in warning times allows us to present a sufficient number of with project scenarios to demonstrate the flexibility of the model.

A uniform distribution that runs from 1 to 24 has been assumed for simplicity. Any number in this range is as likely to be selected as any other. Thus, 4.3 hours of warning is as likely as 15.9, 11.0 or any other amount of warning time.

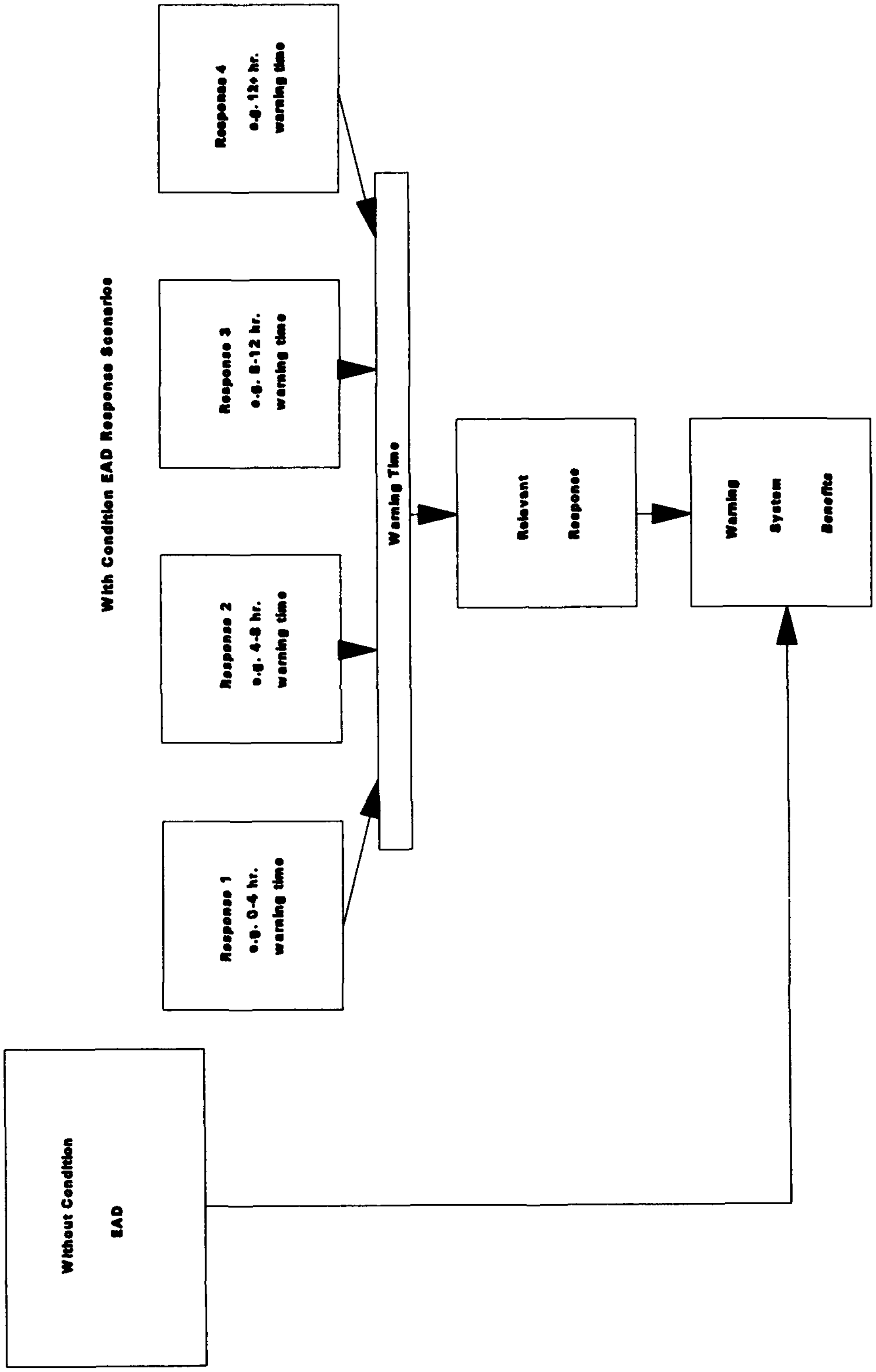

Figure 16
Basic Benefit Estimating Model

In an actual study, the analyst is likely to have a better idea of what the warning time is likely to be.[13] The range probably be narrower, or all values may not be equally likely. Other distributions can be used to describe these circumstances.[14]

Without Project EAD

Data for the hypothetical example have been taken from a single reach of an actual Corps' study. Thus, the stage-damage, rating and frequency curves are realistic. No explicit adjustments were made to the without project condition damage curves to account for the existing level of response to impending floods. It is assumed, for simplicity, that this was done when the data were originally collected.

Damages estimated to occur at each stage can be treated as a known value or they can be allowed to vary according to an analyst-specified distribution. In this example, damages at each stage are assumed to vary according to a normal distribution. EAD are estimated in accordance with the hydroeconomic model of Chapter 2. Appendix 1 provides some discussion of the construction and use of all the models presented in this chapter.

With Project Response Scenarios

Four different response scenarios have been identified for this sample analysis. They are based on assumed warning times of 4 hours or less, 4 to 8 hours, 8 to 12 hours, and more than 12 hours of warning

[13]In some studies, there may be a legitimate concern that no warning will be given. In such cases, there must be some possibility of zero warning time. Within the spreadsheet framework of this model, such a possibility is easily accommodated. Let us suppose there is a 20 percent chance a warning will not be given. We further suppose that if a warning is given the resulting warning time will be uniformly distributed from 1 to 24 hours. The distribution of warning times can be specified as a discrete distribution with, say, a 0.2 probability of a value of zero and a 0.8 probability of a value from a uniform distribution from 1 to 24 hours.

[14]For example, with a minimum, maximum and most likely amount of warning time the analyst has estimates of the three parameters necessary to describe a triangular distribution. Triangular distributions are often used when the actual distribution is not otherwise known. With a single estimate of the mean, an exponential distribution can be described. Add a standard deviation to the mean and a normal distribution can be described. Analysts are cautioned, however, that these distributions are significantly different from one another and there should be some theoretical or empirical basis for the assumed distributions. A Guide to Probability Theory and Application by C. Derman, L. Glaser, and I. Olkin, though out of print, is well worth the search for analysts looking for a good, accessible introduction to probability distributions and their parameters. The book was published by Holt, Rinehart and Winston, Inc. of New York in 1973.

time.[15] The designation of these periods is entirely arbitrary as far as the model is concerned. One can consider 2, 8 or any number of scenarios as easily as one considers 4.

Most studies will include minimum and maximum response scenarios and as many intermediate scenarios as are necessary to describe the significantly different responses possible over the range from minimum to maximum response. A most likely response will usually be included among the intermediate scenarios. The probability or likelihood of the with project response scenarios is dependent upon the warning time distribution.

Each of the four response scenarios leads to a different estimate of expected annual damages with the project. In general, a 4 hour warning is expected to result in fewer damage reductions (i.e., a smaller shift in the damage curve) than a 4-8 hour warning. The model can accommodate other possibilities as well. For example, it is possible that some 4 hour warnings may result in greater damage reductions than a 4-8 hour warning. A 7 hour warning initially given at 1 am may not be as effective in reducing damages as a 4 hour warning given at noon.[16]

Based on the amount of warning time randomly determined from the distribution of warning times, a response scenario is identified as the relevant one for that warning time. For example, if warning times are uniformly distributed from 1 to 24 hours, and a 6.1 hour warning time is randomly selected, the relevant response scenario for this warning is the 4-8 hour response. Expected annual damages obtained for the 4-8 hour scenario are subtracted from the without project condition expected annual damages for this iteration of the model to obtain an estimate of warning and response system benefits.

A single estimate of benefits, so obtained, is obviously not sufficient for identifying project benefits. Warning times can vary from event-to-event. The shift in a damage curve can vary from event-to-event within response scenarios. As indicated in the literature review of Chapter 3, the response to a warning depends on a great variety of variables. Thus, the computation is repeated numerous times.

Damage Curve Shifts

The major difference in the distinct levels of detail (called applications in the sections that follow) at which this model can be used is the method by which the damage curve is shifted at each level. Under

[15]The asymmetric distribution of time across these four response scenarios will figure prominently in the distribution of project benefits later in this chapter.

[16]For example, suppose a 0-4 hour warning can reduce damages from 0 to 5 percent. A simple method of allowing for the possibility of a longer warning resulting in less damage than a shorter warning may produce is to simply allow overlap in the percentage reductions. If the damage reductions for 4-8 hours warning are 3 to 10 percent, it is evident that randomly selected reductions from a longer warning, say 4%, will be less than the reductions from a shorter warning, say 5%, in some cases.

the simplest applications of the model a stage-damage curve is assumed to already be available.[17] The curve is used as is for the without project condition estimate of expected annual damages.

In order to reflect the presence of a flood warning and preparedness system, it is necessary to shift the damage curve. The simplest way to do this is to assume some percentage reduction in damages at each stage. The extent of the assumed reduction in damages used in the model can be determined based on explicit knowledge of the floodplain community, results from similar studies, the literature, a delphi or other consensus building approach, or professional judgment.

The following assumptions provide the starting point for the applications to follow. With 4 hours of warning or less, damages are assumed to be reduced from 0 to 2 percent.[18] These reductions were assumed to be uniformly distributed, i.e., any reduction in this range is as likely as another. For each stage and each iteration of the model, a damage reduction was separately selected. Thus, it is possible that for one iteration of the model, damage reductions at 4 national geodetic vertical datum (NGVD) could be 1.9 percent and reductions at 9 NGVD could be 0.5 percent,[19] while the next iteration could yield the opposite result. For response scenarios of 4-8, 8-12, and over 12 hours of warning time the damage reductions are assumed to be uniformly distributed with reductions of 0 to 4 percent, 2 to 6 percent, and 4 to 10 percent, respectively. These percentages have been arbitrarily chosen to illustrate a range of possible outcomes and should not be considered default values for any real analyses.

Figure 17 shows damage curves for the 4-8 hour response scenario generated during four random iterations of the model. Each curve represents a different shift from the without project condition damage curve.

At the beginning elevation of 1 NGVD there is substantial difference in the damage curves. EAD calculations for the four damage curves shown would reflect widely varying levels of success in reducing

[17]Damages at any stage can vary for a lot of reasons besides the response time. As outlined in Chapter 2, damages depend on a number of variables. To reflect this reality and to encourage similar thinking among Corps' analysts, we have specified a distribution of damages at each flood stage in the without project condition. This means that for each iteration of the model, a different without project condition damage curve was used. The without project damage curve was used for each of the four response scenarios within each iteration, however.

[18]The model multiplies each of the damages at each stage by a number randomly selected from a uniform distribution with a minimum of .98 and a maximum of 1.00. Thus, damages with 4 hours of warning or less range from 98 to 100 percent of the damages without the project. This corresponds exactly to an assumption of uniformly distributed damage reductions ranging from 0 to 2 percent.

[19]Because each stage represents a flood event that is independent of other flood events, we have assumed that damage reductions at each stage should also be treated independently of each other. This is not a necessary constraint of the model and a wide variety of dependencies can be built into the model by making use of Lotus and @RISK programming capabilities.

damages from the frequent minor floods that reach 1 NGVD. Over the range of floods that would reach 2 to 6 NGVD there is relatively less difference in damages. At 7 NGVD and again at 9 NGVD there are substantial differences in damages, despite the fact these curves all reflect 4-8 hours of warning time. The many different variables that affect people's warning response, reviewed in Chapter 3, can be assumed to vary from one event to the next, resulting in the types of variation shown among stage-damage curves in Figure 17. Another four-iteration sample can be expected to result in an entirely different distribution of stage-damage curves.

Figure 18 extends this example by showing the distribution of damage curves for 500 iterations of the model. The mean, one standard deviation, and approximate two standard deviation[20] confidence intervals are shown. Figure 18 can be considered the plan view of a three-dimensional stage-damage distribution. Figure 19 shows a cross section of Figure 18 at an NGVD of 15.

These three figures taken together illustrate a point essential to this model. Damage curves shift in reaction to changes in warning time, as discussed in Chapter 2. Four possible shifts are shown in Figure 17, the range of 500 possible shifts is shown in Figure 18. Each shift has its own probability or likelihood of occurring. This probability of occurrence for possible damages at one elevation is shown by the height of Figure 19.

With project EAD are calculated for each damage curve. Because some damage curves are more likely than others, the EAD resulting from these damage curves will be more likely than other EAD. Similarly, because benefits depend on with project EAD, the likelihood of some benefits will be greater than others. If the calculation is repeated a large number of times, the most likely benefits will show up most often, but the occurrence of extremely low and extremely high benefit estimates will also be observed. The range of benefits obtained ultimately depends on the assumptions built into the model.

The Remainder of the Chapter

Estimation of flood warning and preparedness benefits as presented in this procedures manual is a risk-based analysis. The amount of warning time, the response of people to that warning, and the amount by which they are able to reduce their damages for any specific event cannot be known with certainty. Hence, the extent of the shift in the with project stage-damage curve as compared to the without project curve is uncertain.

The models presented in this chapter provide some options for dealing with this uncertainty. The five applications that follow present different techniques for shifting the damage curve to reflect the effect of a warning on the damage relationship.

[20]The wider confidence limits show the 5 and 95 percent confidence limits.

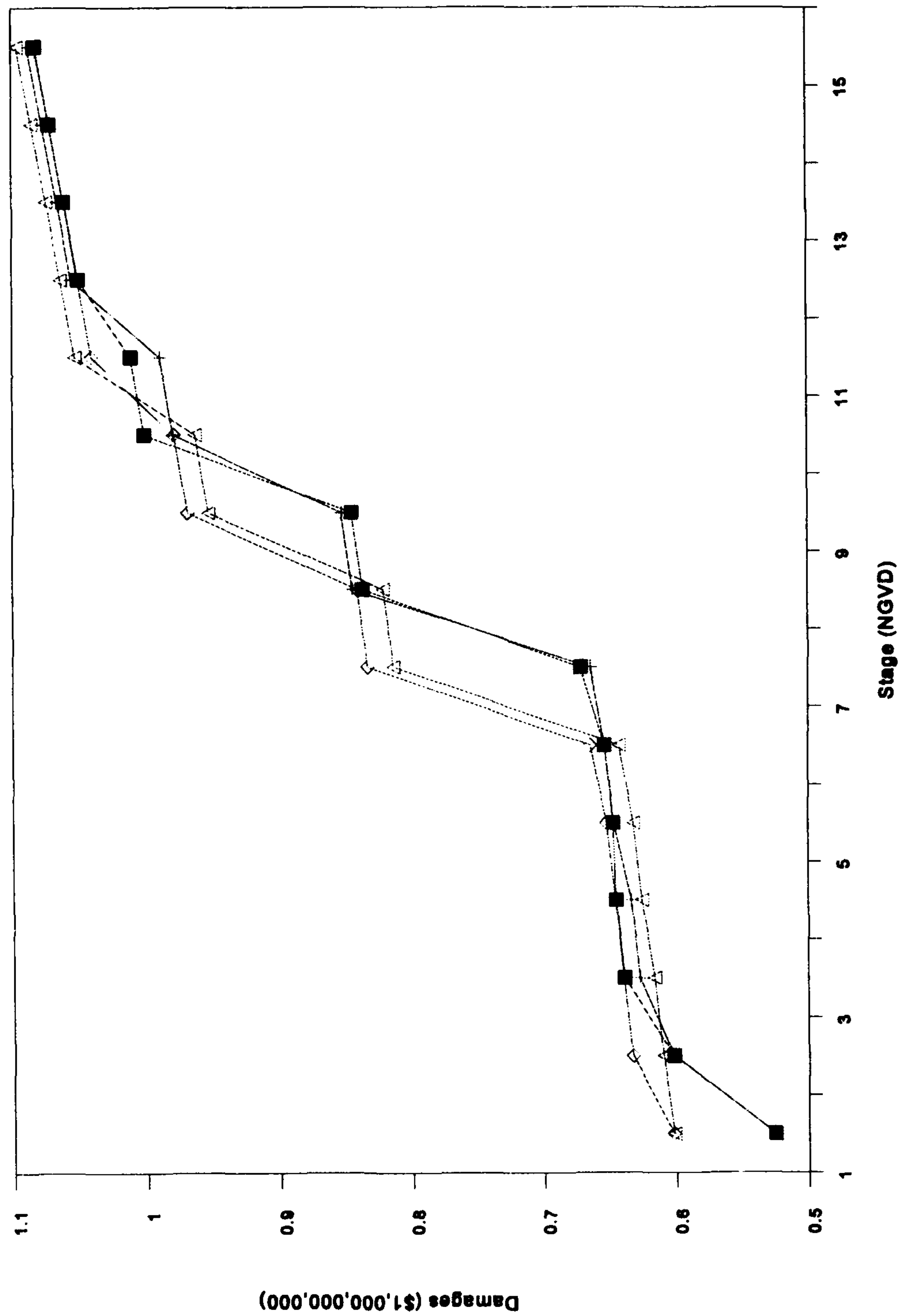

Figure 17
Sample of 4 Random Stage-Damage Curves

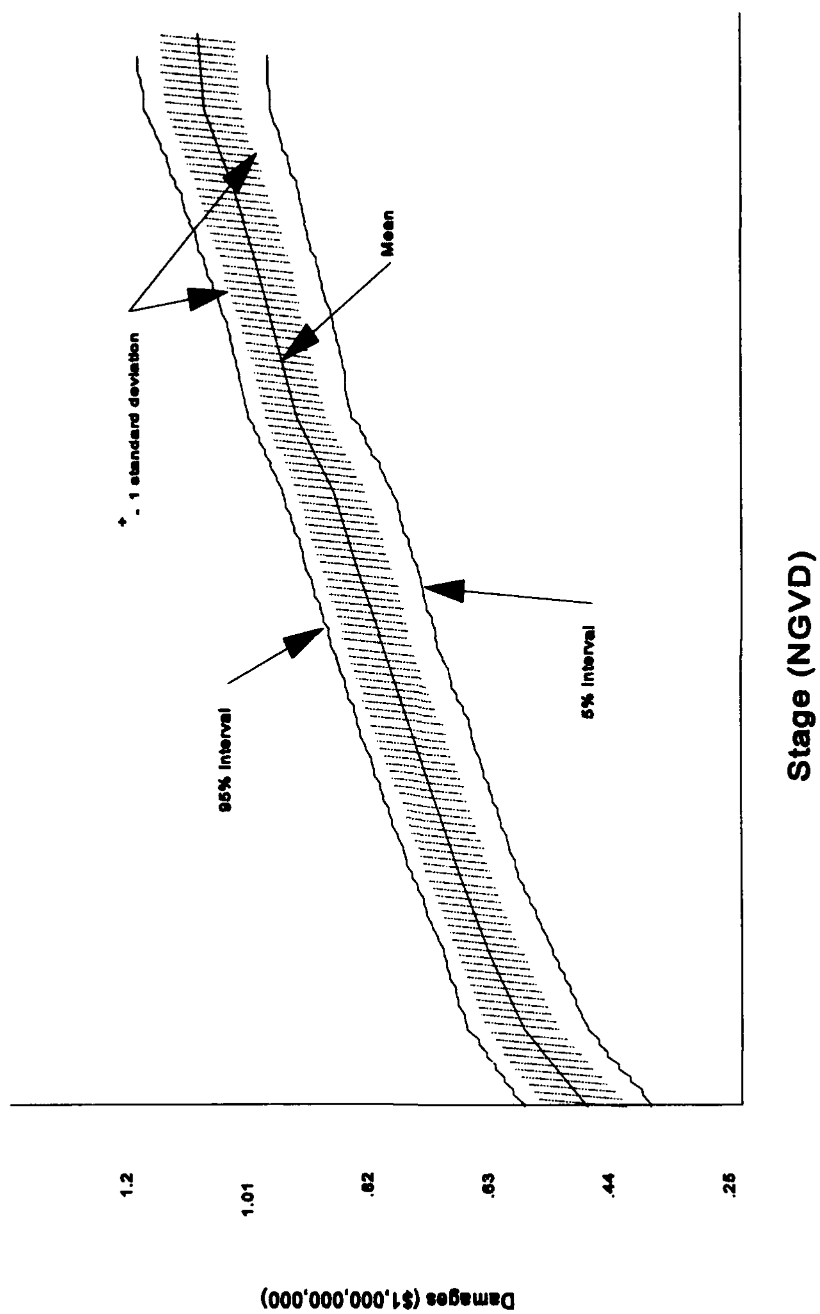

Figure 18
Sample of 500 Random Stage-Damage Curves

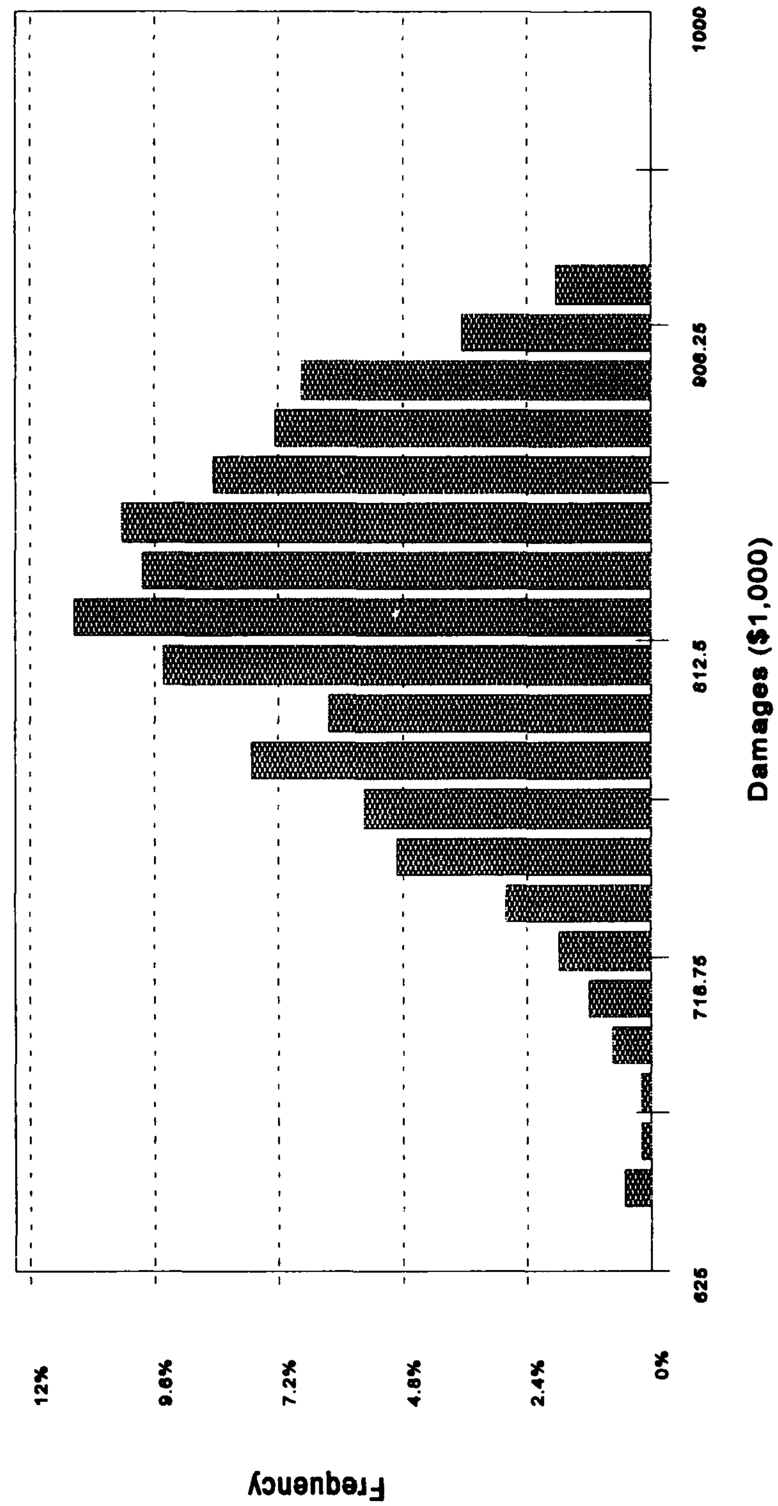

Figure 19
Distribution of Damages at 15 NGVD

APPLICATION ONE (ASSUMED PERCENTAGE STAGE-DAMAGE REDUCTION)

Let's begin with the simplest case where one flood warning and preparedness system alternative is assumed to result in one warning response scenario. With a basic understanding of the literature, knowledge of the community, and exercise of professional judgment, one can simply assume a fixed percentage reduction in damages. Figure 20 shows the with project condition stage-damage curve is assumed to be 4.4% less than the without project stage-damage curve. Expected annual damages without the project are $10,175,000. Expected annual damages with the project and its assumed 4.4% reduction are $9,727,000, resulting in expected annual benefits of $448,000.

This simple application hardly requires a new model. One need only assume the shift in the damage curve. The key, of course, is assuming a reasonable reduction. A 4.4% reduction has been assumed because that was the average reduction obtained in the application that follows, so it lends itself readily to some simple comparisons.

The same percentage reduction in damages need not be taken for every stage of flooding; variable percentage reductions can be taken at each stage.[21] The determinate percentage reduction[22] in the stage-damage curve approach is perhaps most useful when it can be shown that the assumed reductions are considered reasonable by all interested parties and economic feasibility under these assumptions is clear one way or the other.

This type of damage curve shifting can also be used with a distribution of warning times and the varying response scenarios. Each response scenario is defined based on an assumed percentage decrease in stage-damages.

An assumed percentage reduction in stage-damages, whether that percentage varies from flood stage to flood stage or is constant for the entire stage-damage curve, represents a risk-based expected value of damage reductions. As pointed out in the Chapter 3 literature review, there is a wide range of responses people can make to a flood warning Hence, the actual reduction in damages is expected to vary from event-to-event and the identified value is the simplest estimate of an unknown parameter.

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[21]For example, one could assume a 7% percent reduction at stage = 1, a 6.4% reduction at stage = 2, a 2.1% reduction at stage = 5, a 0% reduction at stage = 12, etc. The only constraint is the analyst's ability to discern such differences from stage-to-stage.

[22]We distinguish the determinate percentage reduction from the uncertain percentage reduction. When a single value is assumed to be the reduction of damages, we call that a determinate reduction. This contrasts with the case where damage reductions are expected to fall within some range of values. This latter case is considered to be uncertain, and it is the subject of subsequent applications.

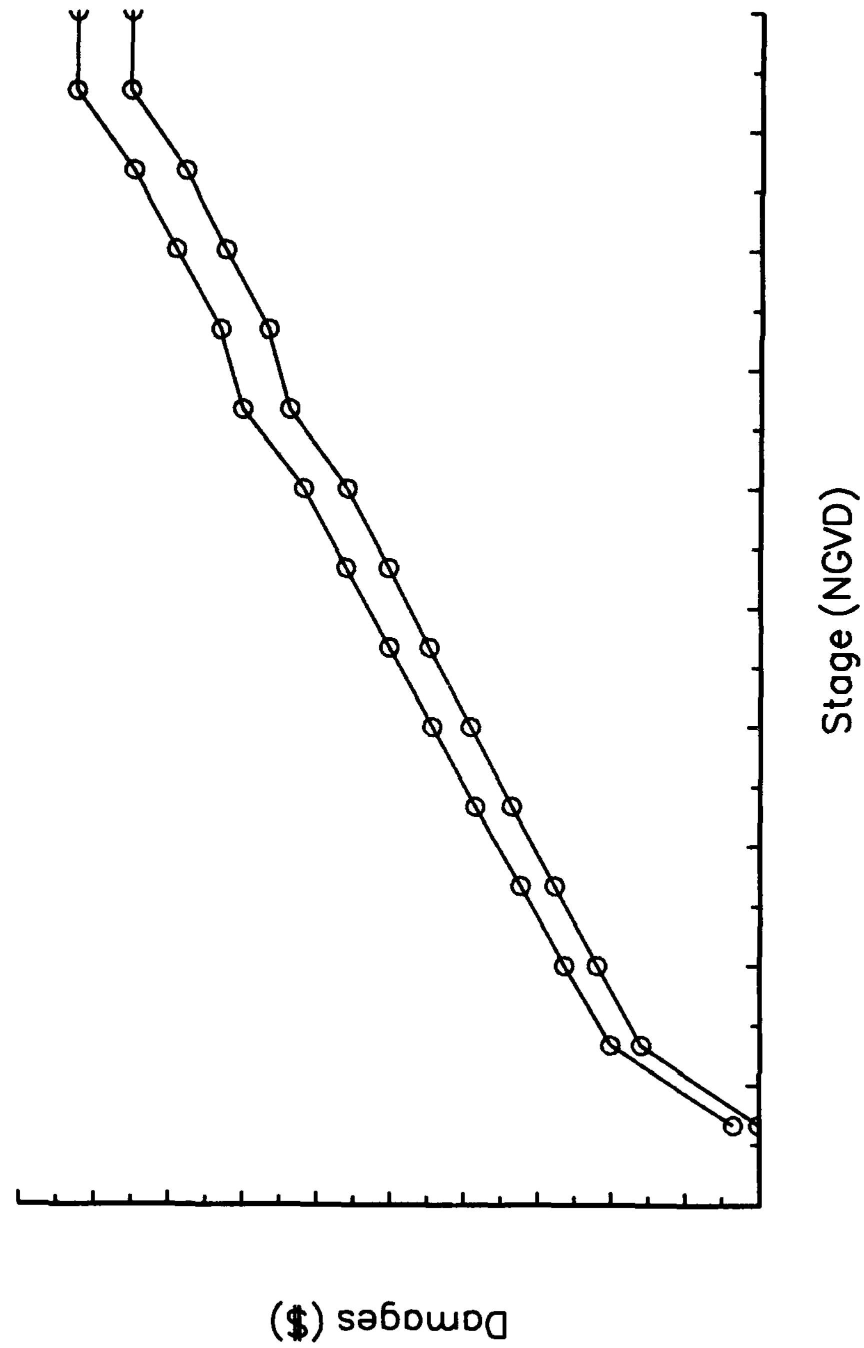

Figure 20
Stage-Damage Reduced 4.4%

APPLICATION TWO (UNCERTAIN STAGE-DAMAGE PERCENTAGE REDUCTION)

This second application improves on the first by admitting that the reduction in stage-damages that results from a warning is unknown. The second application allows analysts to treat the warning time as an uncertain value[23] in the analysis. Warning times were assumed to be uniformly distributed from 1 to 24 hours. Damage reductions for the four responses were as described above, ranging from a low reduction of 0 to 2% to a high of 4 to 10%. A 2,000-iteration simulation using the flood warning and preparedness benefit model was run. A different with project condition stage-damage curve was generated for each iteration (as demonstrated in Figure 17) and used as the basis for calculating EAD with the project. The results described below are from that simulation.

Expected annual benefits for the flood warning and preparedness system ranged from a low of $3,800 to a high of $981,000. These results represent extremes in possible outcomes. For example, if very little warning time is given and people take little action to reduce their damages the benefits could be slight, as small as $3,800. On the other hand, if there is ample warning time and people take effective action, benefits could be close to $1 million.

The distribution of benefit estimates obtained from the simulation is shown in Figure 21. The mean of this distribution, i.e., expected annual benefits of the system, is $445,000. Decision makers are used to seeing a single-valued estimate of project benefits, rather than a distribution, and the mean value of the distribution is that single, best estimate of project benefits.

The distribution presented in Figure 21 is somewhat odd in appearance. The mean, a measure of central tendency, is found in a "slump" in the distribution. The shape of this distribution results from the identification of response scenarios with asymmetric durations. Three of the four scenarios are four hours in duration, the fourth one is twelve hours. Thus, we have, in effect, two distributions overlapping; one from the first three responses, the other from the fourth response. A more symmetric identification of response scenarios can be expected to yield a distribution of benefits that is more normal in shape.

A $445,000 reduction in EAD represents a 4.4% reduction from the without project condition EAD of $10,175,000. The value of the current approach over a straightforward estimate of a 4.4% reduction in damages, as was done in application one, is that the credibility of the analysis doesn't rise and fall on the assumption that damages are reduced by 4.4% (i.e., reviewers, in the former case, might ask why you didn't assume 4.2% or 3.1%?).

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[23]Damage reduction percentages are uncertain for a variety of reasons. One major factor contributing to this uncertainty is the behavioral response to a warning. How many people will receive the message? How many will respond? What will they do? And how can we translate all of this to damage reductions? A 4.4% reduction in damages may be a reasonable assumption but it does not imply that everyone reduces her damage by 4.4%. Rather, it implies that the average reduction across all individuals is 4.4%.

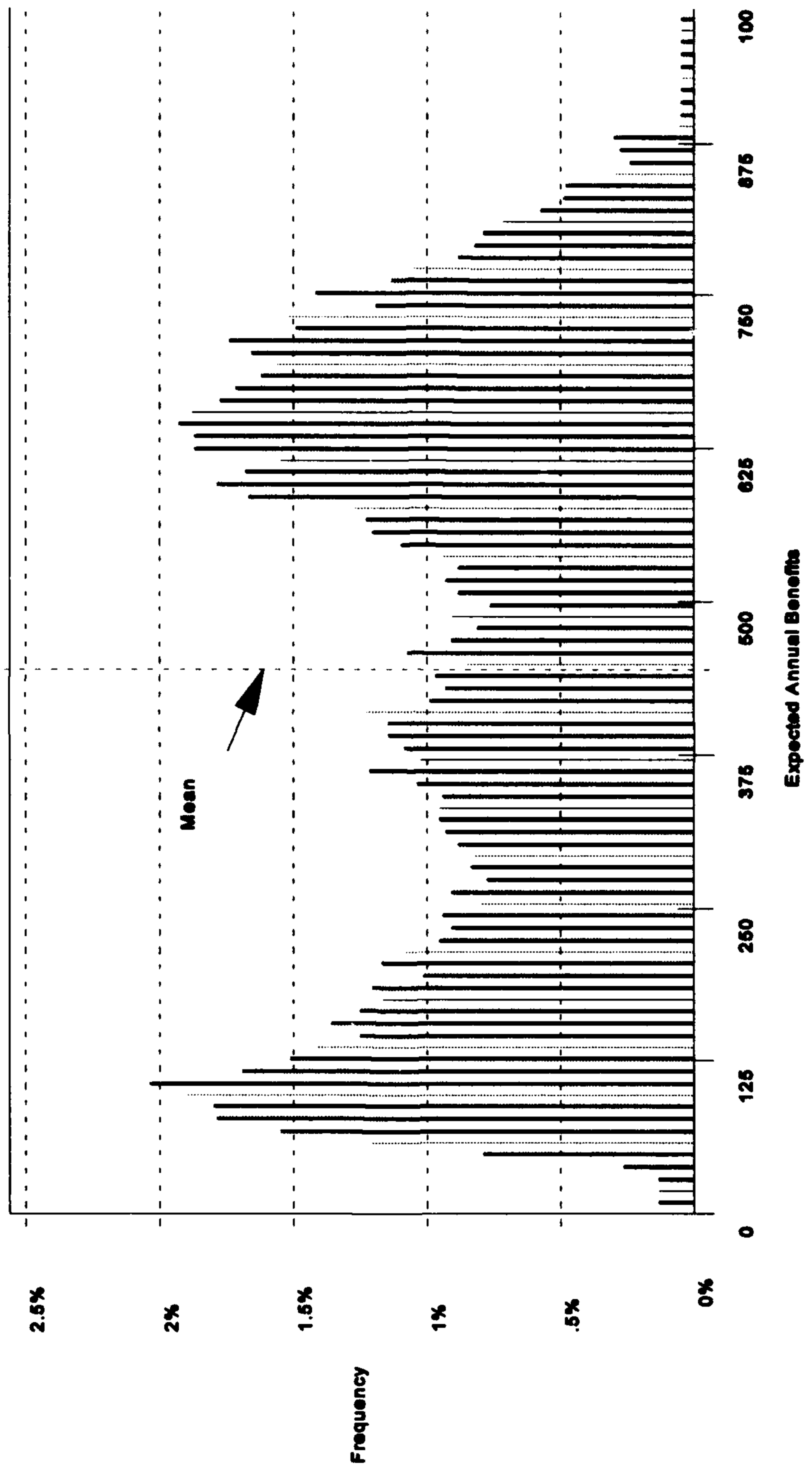

Figure 21
Distribution of Benefits

This approach is one of the simplest and least costly when stage-damage data exists, since the analyst can individually specify the warning time distribution and the range in damage-reductions (i.e,, curve shifting) for each response scenario as a distribution. These ranges of various judgments will ultimately result in benefit estimates. No one assumption need be critical to the benefit estimate as was the case in application one, however.

Any analyst can be more confident of being correct if he can say the reduction will be between "this percent" and "that percent", rather than being required to specify a single reduction as "something point something". Thus, it is preferable to say damages are assumed to be reduced from, say, 2 to 6% rather than to say damage reductions are assumed to be 4.4%. By specifying the nature of the distribution of reductions, the analyst has the opportunity to elevate the likelihood of some values, including 4.4, over others, if appropriate.

MODELING BEHAVIORAL RESPONSE TO FLOOD WARNING

In application two, the analyst enters a distribution of possible damage reductions for each flood stage. It was assumed that the distribution of damage reductions was determined by the analyst. In this section, a method for generating a distribution of damage reductions is offered.

By allowing the analyst to make judgments about specific behavioral responses in the study area, distributions can be generated. The basis for the analyst's behavioral judgments may be detailed knowledge of the study area or reported behavioral responses found in the literature as reviewed in Appendix 2.

There is nothing magical about the modeling of behavioral responses and damage reductions offered in this section. There are many ways to do this; some are complex, others are simple. The response model described here can be made more or less simple by adding or deleting components of the model. Figure 22 describes the construction of the response model. The assumptions described in the following paragraphs are used in Application Three.

The alternative method in this procedures manual for determining percentage reductions to damages at different stages begins with the assumption that certain parts of the warning process are essential to damage reductions. The analyst has considerable leeway in determining what elements of the process are important in the study. The literature reviewed in Chapter 3 provides insight into what are likely to be important elements of any warning system, as well as the variables that are important in those elements.

We begin with the obvious. In order for people to take action as a result of a warning and response system, a warning must be given. There is always some possibility this won't happen. The probability of "no warning" can be discounted by the analyst whenever appropriate. For this example, it is assumed there is at least a 90% chance, most likely a 99% chance, and at most a 100% chance that a warning will be given for any event. Lacking specific knowledge of the distribution of these different likelihoods, a triangular distribution with a minimum of 0.9, a most likely value of 0.99 and a maximum value of 1.00 is assumed.

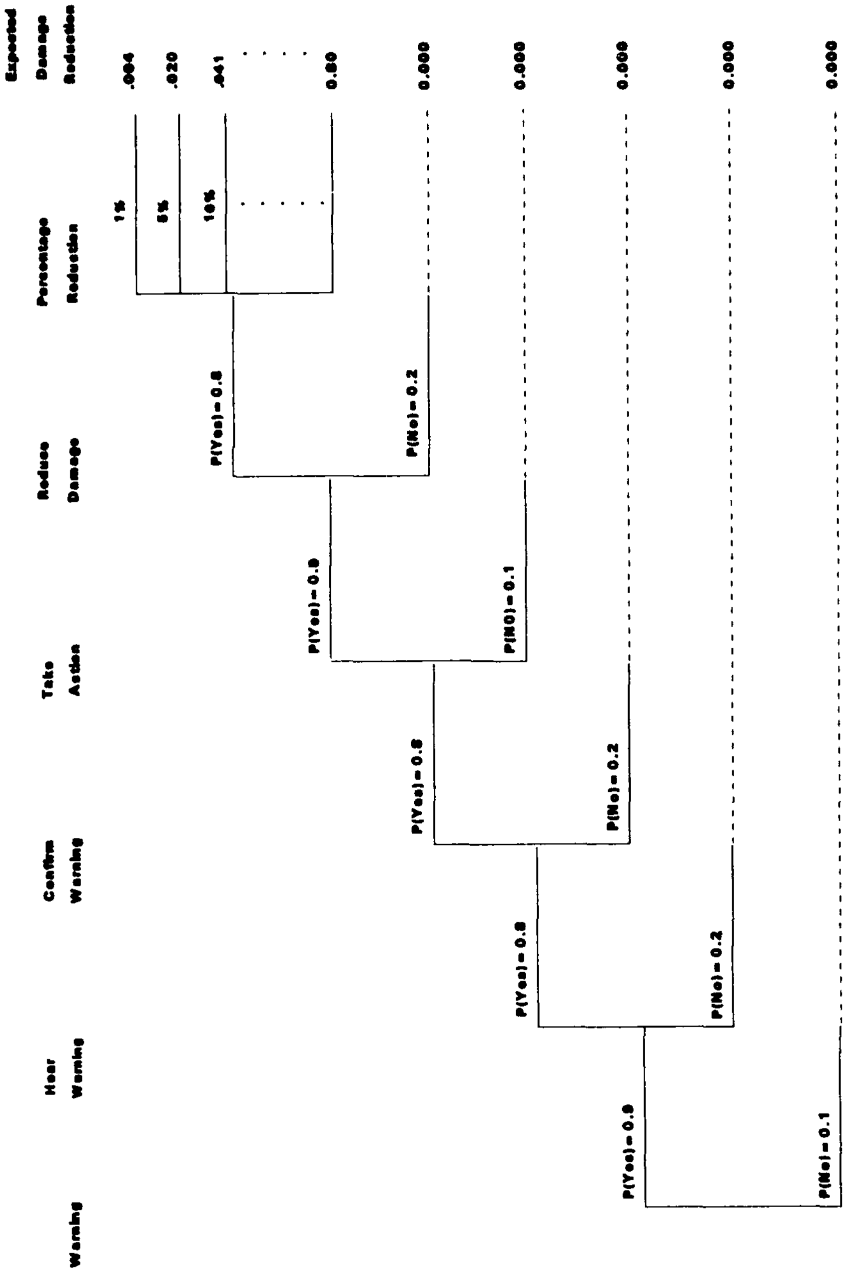

Figure 22
Response Model Event Tree

The probabilities of a warning being issued depend on the type of system. Visual inspection systems that depend on human observation and reporting are more likely to fail to result in a warning than other systems. As redundancy is added to a system the probability of no warning decreases.

The literature suggests that not everyone hears a warning. The elderly are one group known to hear warnings less frequently than other groups, all other things equal. The analyst can adjust the proportion of people who hear a warning (or equivalently, adjust the probability that any one person will hear the warning) up or down depending on the characteristics of the population served by the system that affect its likelihood of hearing warnings. The literature is one source of general information on this topic.

We have assumed that no less than 80% and no more than 97% hear the warning, with 90% of the people most likely hearing a warning.[24] Once again, these three parameters were used to describe a triangular distribution.

It is worth noting that the proportion of people hearing a warning could be explicitly expressed as a function of as many other variables as the analyst chooses. Thus, the probability of hearing a warning could be conditioned on the age, race, sex, income, location, occupations, etc. of a community. Such modifications can be accomplished in complex ways using precise mathematical functions or, more simply, these functions can be streamlined by assumptions.

Confirming the validity of the message appears to be as close to an example of universal behavior as can be found in the literature. It is assumed that taking effective action depends on a person's ability to confirm the warning message. To this end, it is assumed that between 80 and 95% of all people who hear the warning are able to confirm it. It is assumed any percentage in this range is as likely as any other. Thus the probability of confirming a message is uniformly distributed over this range.[25]

The percentage of people who are able to confirm a message will depend on the geographic dispersion of people and the provisions the warning system makes for opportunities for people to confirm a message. For example, a flood warning and preparedness alternative that concentrates on the hardware, to the exclusion of the behavioral aspects of the flood warning and preparedness process, will likely have smaller percentages of people hearing and confirming messages. A planning process that pays attention to behavioral details can be expected to produce more benefits. If planners provide procedures for

[24]This is equivalent to saying there is a probability of at least 0.8 that any one person will hear the warning and at most a probability of 0.97 that any individual hears the warning. Our best estimate of the probability of a person hearing the warning is 0.9.

[25]The assumptions made in the hypothetical examples were usually chosen to facilitate discussion of the model. A uniform distribution is chosen here, more to illustrate that one need not always use a triangular distribution. The parameters used in the distributions are arbitrarily chosen to assure a variation in the range of results rather than to represent realistic values. We have purposely avoided the use of "reasonable" and "representative" default values to avoid prejudicing the analysts judgment of these values.

disseminating messages, proven effective message formats, opportunities for confirmation through multiple media, etc., the percent of people hearing and confirming the message will be higher.

Once a warning is confirmed, not everyone will take action. It is assumed that from 90 to 100% of all people will take action. A uniform distribution was assumed. Of those who take action, not all actions taken will be effective in reducing damages. Some people will not know what to do to prepare for the impending flood; others will pour their energy into gathering their families and preparing to evacuate. Of those who take action, it is assumed that 80 to 97% will take effective action, with 94% the most likely proportion that will take effective action. A triangular distribution was used to describe this response.

The components of the model to this point serve to identify the expected portion of the population at risk that takes effective action. Assuming the events described above to be independent of each other, an estimate of the expected probability of an individual taking effective action can be obtained as the product of all the events:

(1) P(warning)*P(Heard)*P(Confirmed)*P(Action)*P(Effective) = P(Any individual takes effective action)

Using the minimum probability presented for each event, one can obtain the following probability that any individual takes effective action to reduce damages as a result of a flood warning and preparedness system:

(2) $0.9 * 0.8 * 0.8 * 0.9 * 0.8 = 0.41$

This means there is a 0.41 chance that any individual will take effective action. Alternatively, it can be interpreted to mean 41% of the community takes effective action.

The analyst has two basic choices in modeling the effects of such behavioral responses on system benefits. First, he can make adjustments to individual damage curves or classes of individual depth-percent damage curves (e.g., structures with two stories and no basement) or second, he can make adjustments to the entire stage-damage curve or types of stage-damage curves (e.g., residential, commercial, etc.). For now, adjustments will continue to be made to the total stage-damage curve. Adjustments to individual damage curves will be demonstrated in application five. Thus, the probabilities assumed for the components of the model reflect average behavior for all floodplain occupants rather than the probability of any one individual taking effective action.

The next critical step in developing this refinement of the model is to estimate the damage reduction percentage that results from the effective action taken. The average damage reduction of all people who take effective action is uncertain but is assumed for this example to have a uniform distribution over a range of 0.5 to 15%.

Multiplying the proportion of people taking effective action given by equation (1) by the percent reduction in damages, yields the expected damage reduction, as shown in equation (3).

(3) Expected damage reduction = P(Any individual takes effective action)*(Average damage reduction percentage)

For example, if there is a 0.41 chance a person will take effective action and that effective action will reduce damages by 10% then the expected damage reduction is 4%:

(4) $0.41 * 0.1 = 0.04$

The diskette included with this report contains a spreadsheet model that performs this calculation. The strength of this approach over that described in applications one and two is that it takes more variables explicitly into account. By recognizing more of the warning process it is possible to be more realistic about the uncertainty surrounding each of the variables.

Results are no longer as sensitive to the single assumption about the percentage of damage reductions or to the assumed distribution of damage reduction percentages. It is also possible to calibrate the model separately for each response scenario considered. It is reasonable to expect that the more advanced the first warning, the more opportunities there are to update and reenforce the warning message. This provides more opportunities for the warning to be heard, confirmed and effectively acted upon.

Table 3 presents the results of a series of 1,000-iteration simulations of the damage-reducing response to a flood warning for the four response scenarios described previously. Distributions of expected damage reductions obtained from these simulations are shown in Figures 23 through 26. T ( ) indicates a triangular distribution with minimum, most likely, and maximum parameters given in the parenthesis. U ( ) indicates a uniform distribution with the minimum and maximum parameters given in parenthesis.

No difference in the probability of warning being given is assumed in each of the scenarios. All other assumptions reflect the fact that as the amount of available time increases more people are able to hear, confirm, and act effectively on the warning. The expected damage reductions (EDR), shown in Table 3, average 0.1%, 2.6%, 4.9% and 9.7% for the four scenarios examined.

APPLICATION THREE (UNCERTAIN BEHAVIORAL STAGE-DAMAGE RESPONSE)

The preceding applications were after-the-fact analyses of a flood warning and preparedness system appropriate for cases where: the data were collected without thought to the special requirements for analyzing a warning system; where file data are available and the magnitude of the project budget does not warrant detailed study; or, there is simply not enough time or money to do a more detailed analysis.

Though these circumstances may describe a large number of planning circumstances, they do not describe them all. There are situations in which some, but not all, data may exist. That data may include a stage-damage curve, a simple structure count, residential damage estimates only, or any number of other possibilities. In this application, we concentrate on an approach for estimating expected percentage reductions of damages based on knowledge of relevant behavioral factors. The results of the previous section are used to define distributions of damage reductions in this application.

Using the mean and standard deviation from the results of the simulations summarized in Table 3 triangular, normal or other distributions of possible expected damage reductions can be described. These distributions can be used in lieu of the assumed uniform distributions applied in the previous example.

Table 3
Response Model Assumptions and Results

	Less than 1	1-8	8-12	Over 12
Warning given	T(.9, .99, 1)	T(.9, .99, 1)	T(.9, .99, 1)	T(.9, .99, 1)
Hear warning	T(.5, .75, .9)	T(.7, .85, .95)	T(.8, .9, .97)	T(.8, .95, .97)
Confirm	U(.65, .8)	U(.75, .9)	U(.8, .95)	U(.9, .98)
Take action	U(.6, .95)	U(.8, .98)	U(.9, 1)	U(.95, 1)
Reduce damage	T(.5, .75, .95)	T(.7, .85, .95)	T(.8, .92, .97)	T(.9, .95, .99)
% Reduction	U(.0005, .05)	U(.005, .1)	U(.005, .15)	U(.15, .5)
Results				
Mean EDR	0.72%	2.59%	4.96%	24.63%
Minimum EDR	0.01%	0.23%	0.30%	10.00%
Maximum EDR	2.11%	6.43%	11.19%	43.51%
Standard Deviation	0.45%	1.41%	2.73%	7.80%

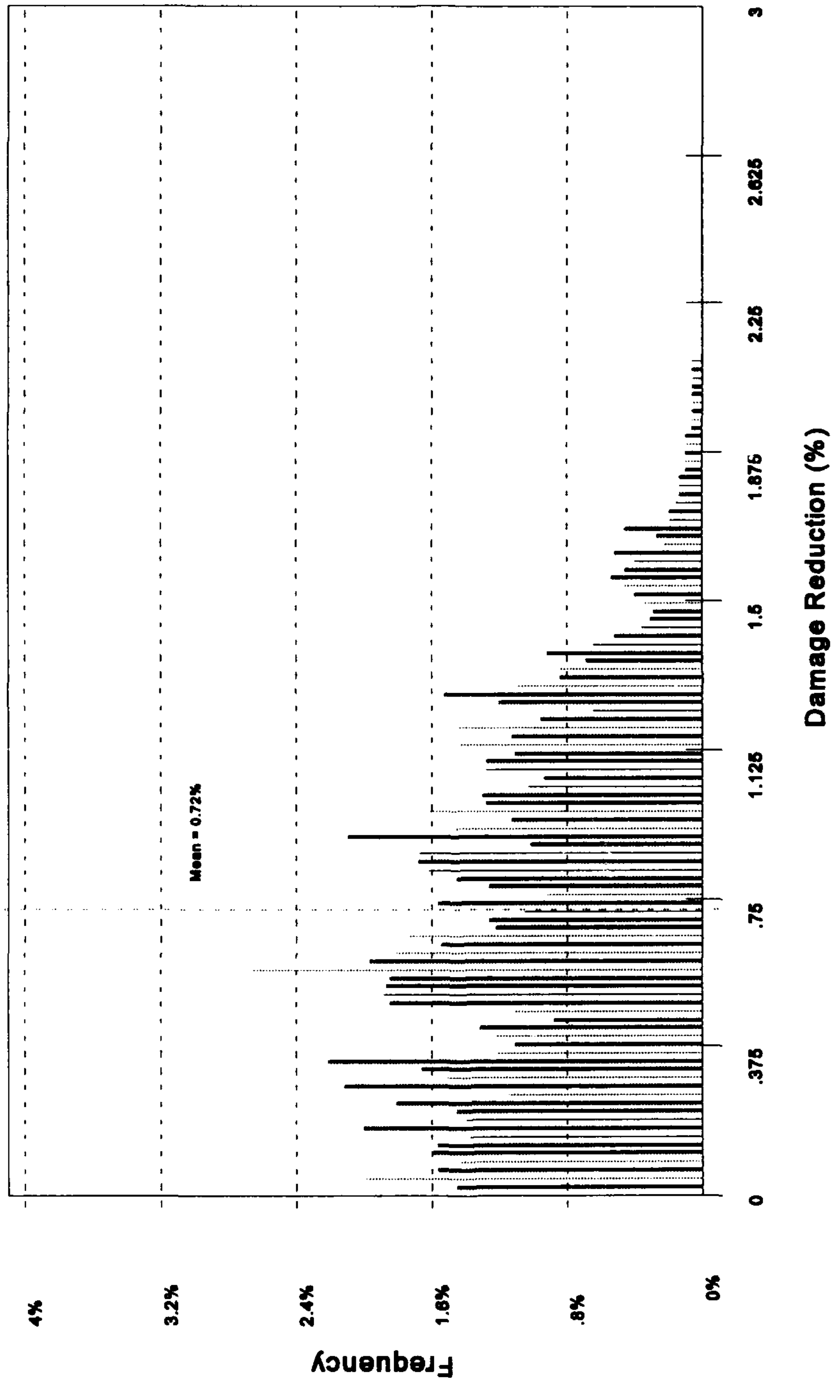

Figure 23
Expected Damage Reductions
With 0-4 Hours Warning

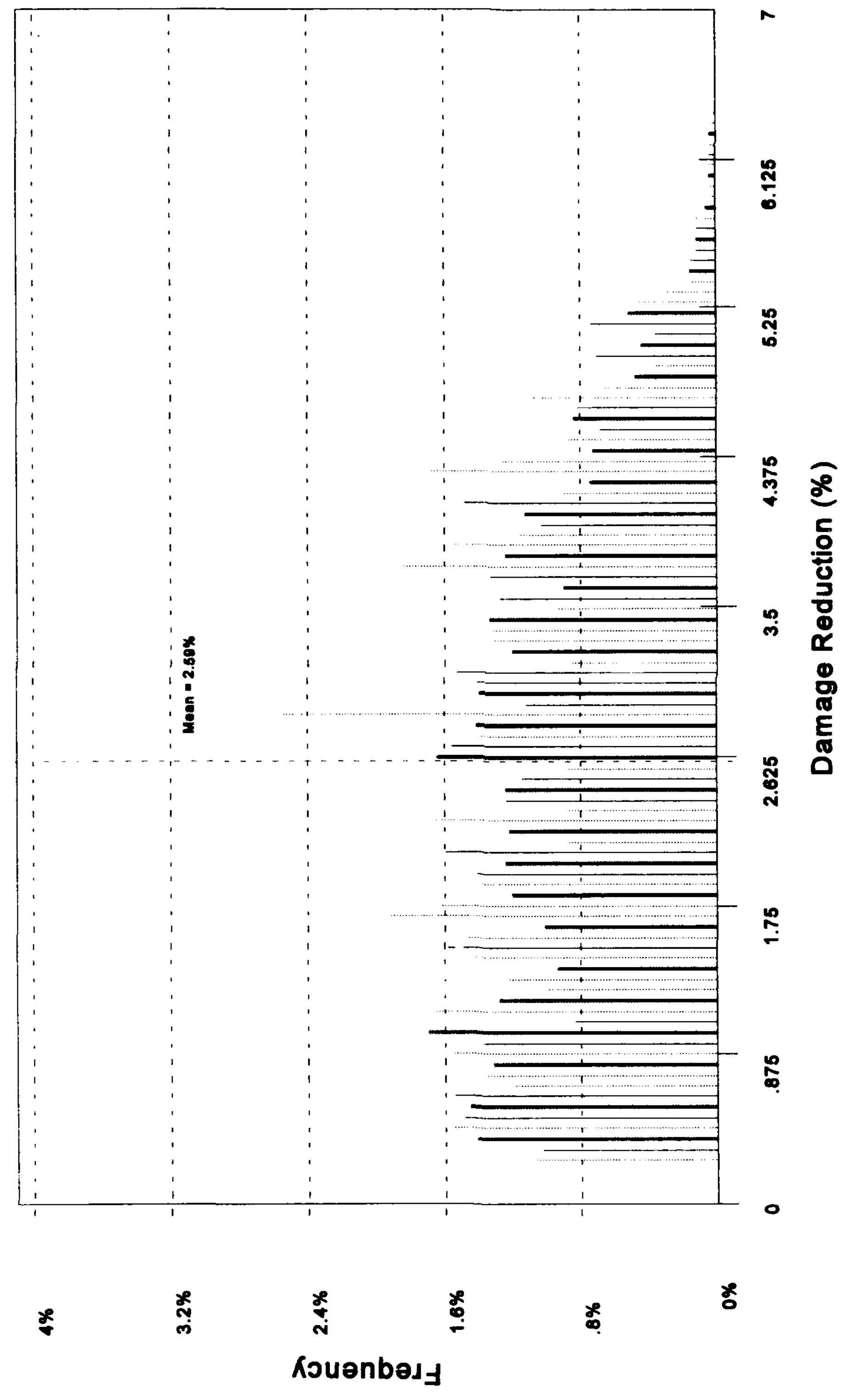

Figure 24
Expected Damage Reductions
With 4-8 Hours Warning

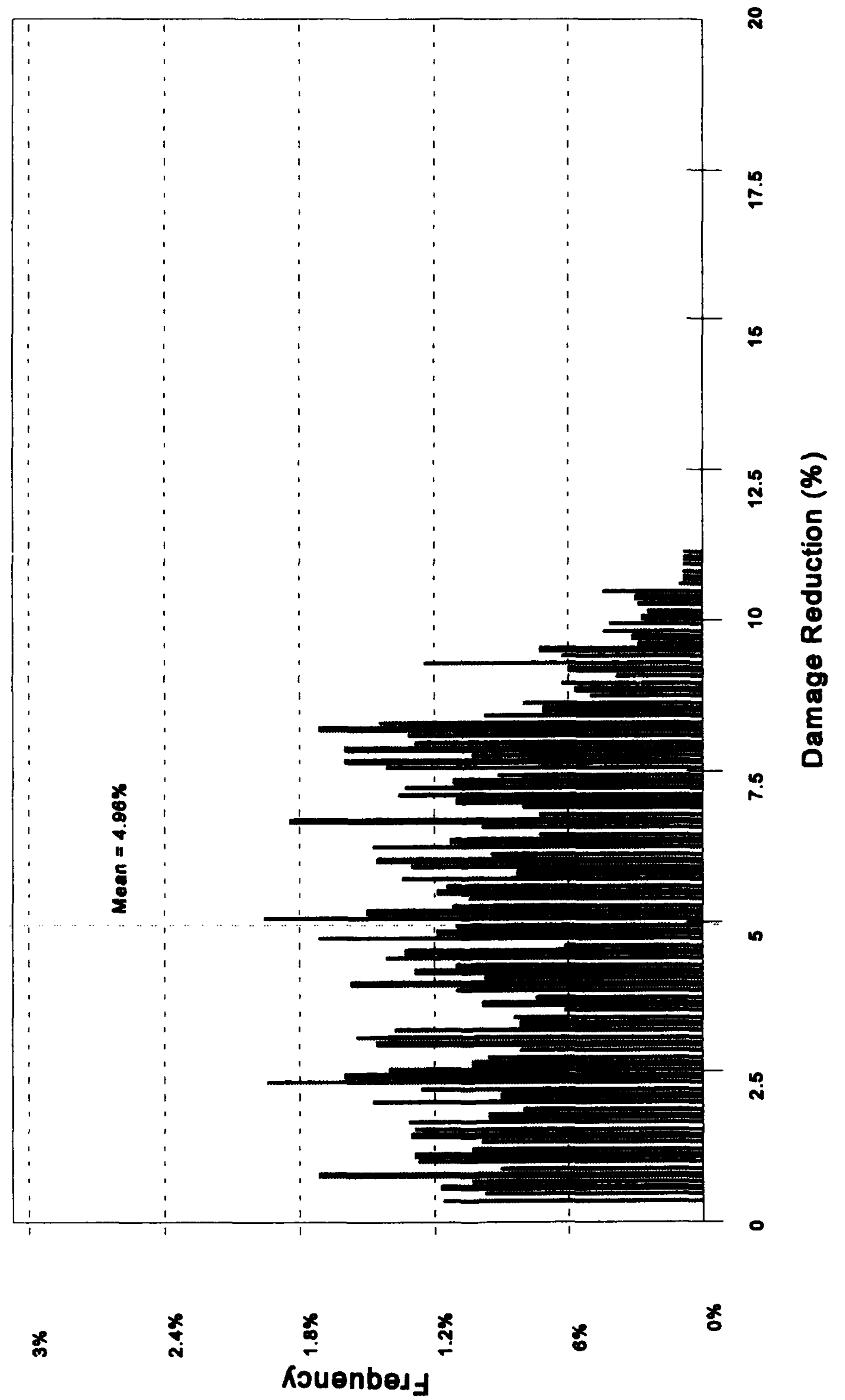

Figure 25
Expected Damage Reductions With 8-12 Hours Warning

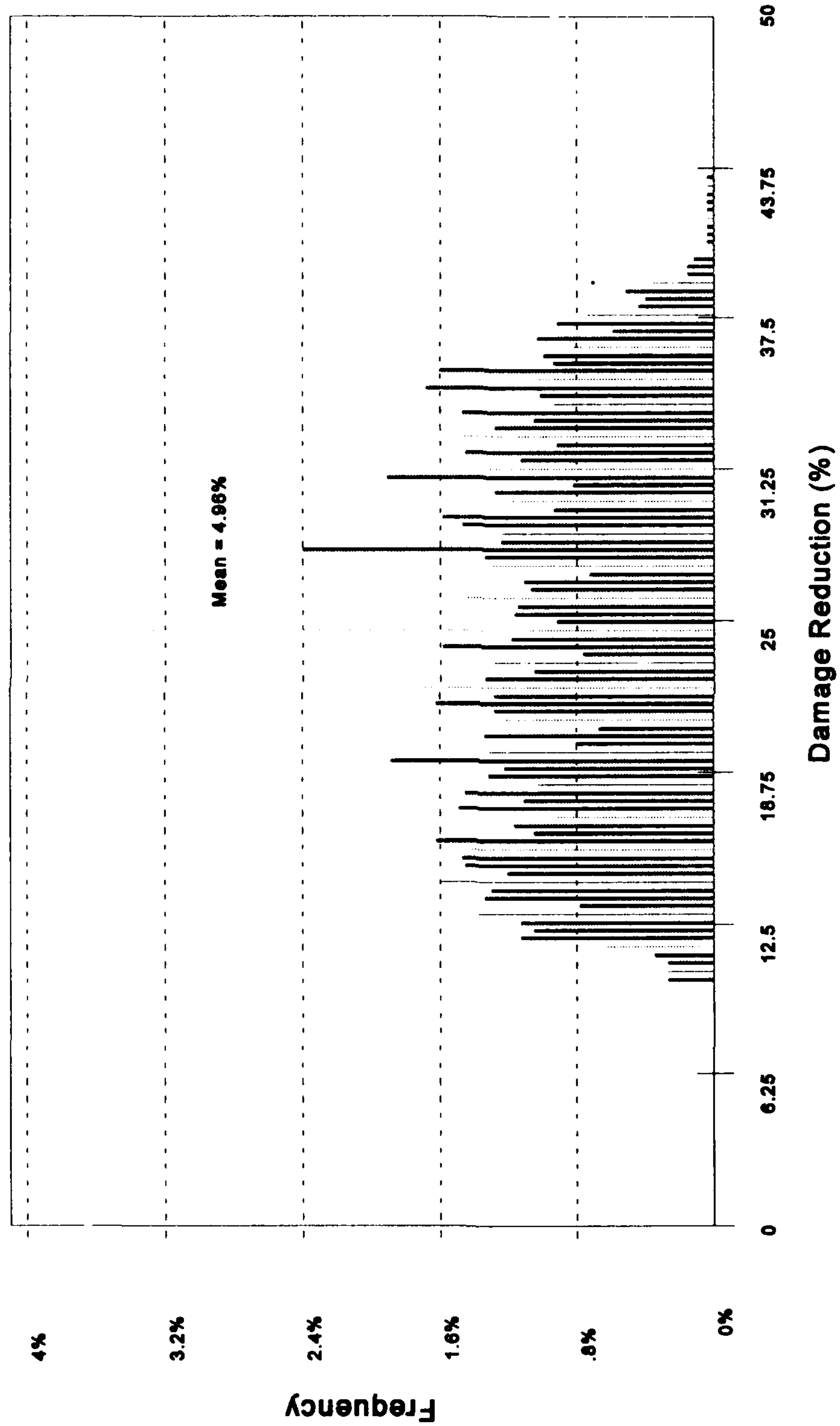

Figure 26
Expected Damage Reductions With Over 12 Hours Warning

Two 2,500-iteration simulations of flood warning and preparedness benefits were run. The first one assumed triangularly distributed damage reductions using the results from Table 3 to identify parameters. The second simulation assumed a truncated normal distribution with the mean and standard deviation above. The distribution is truncated at 0 and 1 (or 0 to 100 in percentages), to force the values to fall within the range of permissible percentage reductions.

Table 4 presents the results of the two simulations. The first simulation, based on triangular distributions, yields mean expected annual benefits of $686,000, with a range of about $1.7 million. The second simulation, based on truncated normal distributions, yields mean expected annual benefits of $652,000, with a range of over $1.8 million.

TABLE 4
Benefit Estimates
Response Model Simulations

	Triangular Distribution	Truncated Normal Distribution
Mean	$ 686,000	$ 652,000
Minimum	0	0
Maximum	1,671,000	1,827,000
Standard Deviation	412,000	412,000

The truncated normal distribution mean is about 5% less than the triangular distribution mean in this case. The significance of this difference will depend on the circumstances of the study and the costs of the warning and response system. The assumed distribution can make a difference, however, so the distribution chosen should be selected based on empirical or theoretical criterion, or a sensitivity analysis should be conducted as was done here.

APPLICATION FOUR (PARALLEL STAGE-DAMAGE SHIFTING SCENARIO)

A recent IWR report (Jack Faucett Associates 1990:77) indicates that one Corps District has estimated benefits to flood warning and preparedness systems by assuming that on average, people would raise the contents of their structures by one foot. By affecting a parallel one-foot downward shift in the damage curve, benefits can be estimated. Shifting the without project condition damage curve of the first three applications down one foot yields project benefits of $839,000, substantially higher than the other methods considered so far. A two-foot shift yields benefits of $1,659,000.

The model can be modified to account for different average content-raising scenarios. For example, with less than 4 hours warning people might be assumed to, on average, raise their contents by one foot. With 4 to 8 hours warning the average could increase to 1.5 feet, etc. Thus, the damage curves in each response scenario would represent a different parallel shift in the demand curve.[26]

Allowing for a legitimate role for professional judgment in the estimation of benefits, this approach suffers a weakness that others do not. As shown in Figures 10 and 14, it is quite likely that the stage-damage curves with and without a project will coincide at greater depths when raising contents is the only or primary method of response to the warning. Thus, assuming a downward shift throughout the domain of the damage curve may be conceptually flawed.

SHIFTING INDIVIDUAL DEPTH-PERCENT DAMAGE CURVES

Up until this point, the options explored for shifting the damage curve have focussed on ways to shift the stage-damage curve. The applications discussed have treated the damage curve as if it was only content damage. Complications introduced by considering further disaggregation of the damage curve have been avoided without weakening the applicability of the model. In practice, the techniques described may have to be applied separately to commercial, residential or other land uses. Some analysts may prefer to treat structural, content and other types of damage separately within each land use category. These are more or less book keeping matters well known to experienced analysts.

There are cases where it would be appropriate to consider the damage curve shifting effects of a warning system on an individual structure basis. One such case is where it is known at the outset of a study that flood warning and preparedness systems will play a significant role in the formulation process and there are sufficient resources to conduct the required analysis. The basic technique is not so different from that applied to the stage-damage curves in the applications above.

Consider a typical residential property. Figure 27 presents 1973 Flood Insurance Administration content and structure depth-percent damage curves for a two-story house with no basement. This curve could be shifted by any of the methods described in applications one through four above. One could reduce the content damage at every stage by some fixed percentage. Content damage at each stage could be reduced by a different percentage. Then one could do the same to the structure curve using different percentages.

The curves could be shifted down a half foot, a foot, two feet. One could use available information from other studies, the literature, expert opinion and professional judgment to create a distribution of

[26]Shifting the total stage-damage curve was done here as a matter of convenience. If this technique is used it would be more appropriate to go into the individual structure data for the flood plain and shift each structure's damage curve by one foot. This can be done by simply changing the structure's first floor elevation and/or ground level elevation. When the revised stage-damage curve is compiled we would not expect a parallel shift.

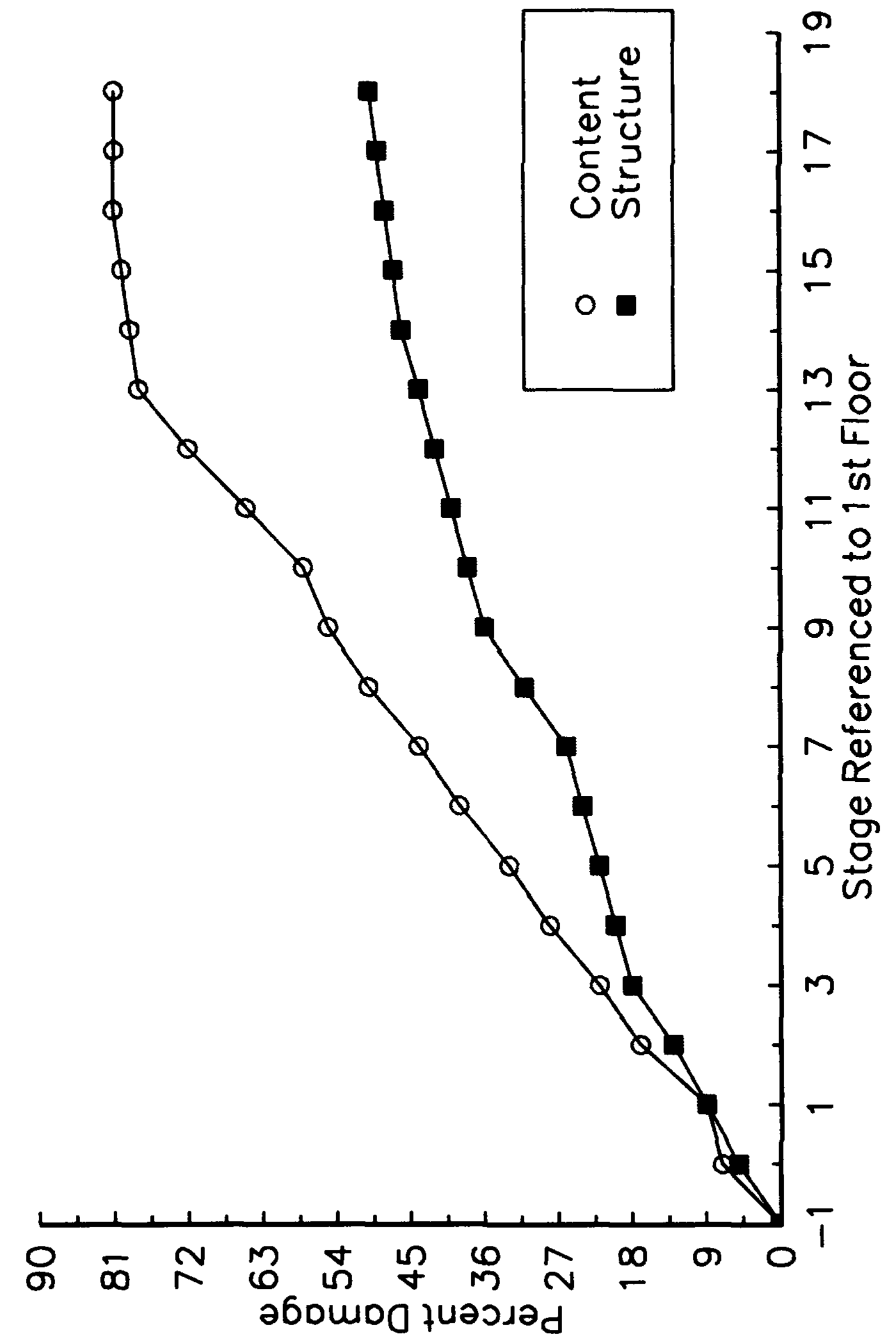

Figure 27
FIA Content and Structure Curves

percentage damages at each stage.[27] Though the options are many, the basic task is to shift the depth-percent damage curve downward to reflect damage reducing behavior that results from additional response time.

APPLICATION FIVE (DEPTH-PERCENT DAMAGE REDUCTION)

This application follows the same basic method described in the first three applications above. For each flood stage there is a distribution of damages. The distributions in this application are distributions of damage percentages rather than of damages or reductions in damages as described in earlier applications. The method used to develop the distribution of damages is an example of one approach to identifying damage reductions for individual structure types.

While earlier applications are applied stage-damage curves that were built up from individual damage relationships, this application begins with those individual relationships. Some Corps Districts have developed depth-percent damage curves specifically for a study area. One method for developing these curves involves entering homes and cataloguing the value and location of the contents of the most common structure types. An estimate of the average total value of all contents can be prepared from this survey. Using professional judgment, items that would be damaged by floods of varying depths are identified. The lost value of these contents are accumulated and expressed as a percentage of the total value of contents. For example, suppose a survey determines a house has $40,000 in contents.[28] If two feet of water on the first floor is judged to cause $10,000 in damage this is 25% damage at +2 feet.

If flood warning benefits are going to be evaluated, the ideal approach would be to gather the necessary information at the time of the development of the depth-percent damage curve. The typical survey instrument is a room-by-room listing of the contents of the house. It would be a simple matter to indicate which items are readily movable, movable with sufficient time, and immovable. Alternatively, it may be feasible to ask the occupant what items would be moved: "if you had one hour of warning, four hours of warning, etc." This information could subsequently be used to construct estimates of depth-percent damage curves under various response time scenarios.

Continuing the example above, if 5 hours of warning time would reduce damages at +2 from $10,000 to $5,000, content damages at +2 would fall from 25% to 12.5%, thus shifting the damage curve

[27]For example, with 7 feet of water on the first floor FIA estimates 44% loss of the value of the structure's contents. With a system in place we might estimate the damage as ranging from 40 to 44% of content value.

[28]Alternatively, the value of a structure's contents is often expressed as a percentage of the structure's value. Thus, contents worth $40,000 in a $100,000 house would result in a content-to-structure ratio of 40%. The examples provided can be readily illustrated in this framework, but the extra step of converting content damages to a percentage of structure value would unnecessarily complicate the example. Therefore, we treat content damages as a percentage of the total content value despite the fact that many stage-damage models do not handle contents in this fashion.

downward. Potential reductions in structure damage could also be investigated at the time of the original survey and handled in a similar manner.

These adjustments must be made to the individual structure's depth-percent damage curve. For example, the depth-percent damage curves entered with the SID-EAD model would be different without and with the project. In Figure 28, the without-project condition content damage curve would be used for the no warning system scenario, the with-project condition curve reflects the system in place.

Constructing such curves requires some additional thought, however. If everyone in the floodplain hears the warning and moves everything that is movable, one would observe the maximum possible reduction of damages. This would result in the maximum shift of the damage curve. Clearly, this will not happen except under abnormal circumstances. Not everyone will hear the warning and among those who do, relatively few will minimize their damages. Only some proportion of the population will act and they will reduce their damages only some proportion of what is possible.

For example, let us assume that at a stage of +2, damages in a single structure could be cut by 50%, from $10,000 to $5,000, as above. Let's assume that 90% of the population hears the warning and acts. So far 90% of the 50% reduction, or 45%, could be achieved. But we know that not everyone will realize the maximum reduction of 50%. If, on average, people will take 80% of the actions available to them to reduce damages[29] then 80% of 90% of 50% or an estimated 36% damage reduction is obtained. Hence, damages with a system in place would fall from $10,000 to $6,400, a 36% reduction. The percent damage would fall from 25% to 16% rather than to the 12.5% in the example above.

Included on the enclosed diskette is a simple model that provides an example of how the above described adjustment can be made for one given warning/response scenario. The example uses the 1973 FIA curve for a two-story residence with no basement. Table 5 shows the columns included in the model. Stage is simply the amount of water, in feet, on the first floor of the structure. Structure damage is expressed as a percentage of the structure's market value. Content damage is expressed as a percentage of the market value of the structure's contents.

The maximum reduction in content damages is the key parameter for this model. At a stage of +2, content damages are 17%. If everyone in the floodplain eliminated all of their content damages the maximum reduction would be 100%. Thus, it is in this column that adjustments, as described above, are entered. The values entered in the sample program were arbitrarily chosen and have no particular significance.

The weighted damage curve of column 5 is the output of the model. It is obtained by specifying some distribution of possible percentages of content damage at each stage. For example, at a stage of +2, without project condition damages are estimated to be 17%. This is the without project condition damage

[29]The reasons for this would depend on the community under study. For example, the inability to realize the fullest possible reduction could be due to age, lack of automobiles, the number of single-parent families, etc.

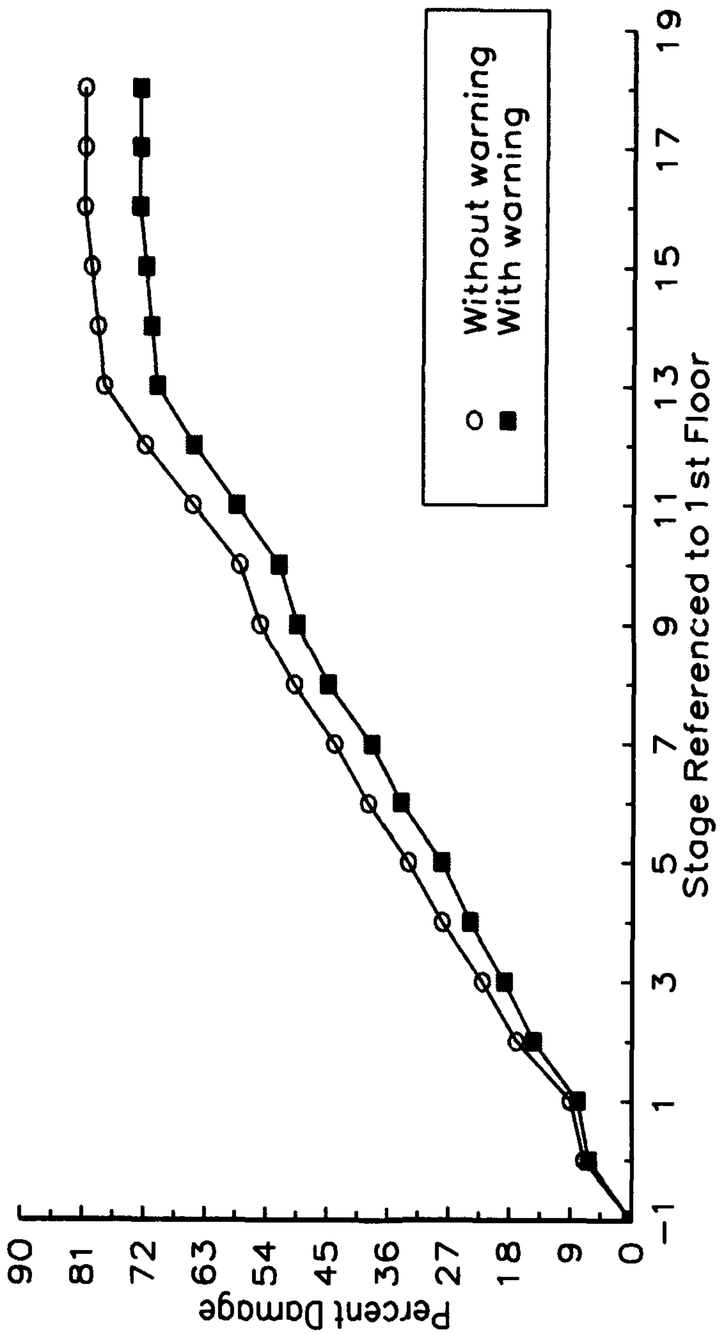

Figure 28

Content Damage With & Without Warning

Table 5
Percent-Content Damage Estimating Model

NGVD	% Structure Damage	% Content Damage	Max. % Content Damage Reduction	Weighted % Conent Damage
(1)	0	0	0	0.00
0	5	7	20	6.300
1	9	9	25	7.875
2	13	17	30	14.450
3	18	22	30	18.700
4	20	28	30	23.800
5	22	33	30	28.050
6	24	39	25	34.125
7	26	44	25	38.500
8	31	50	20	45.000
9	36	55	20	49.500
10	38	58	20	52.200
11	40	65	20	58.[illegible]
12	42	72	20	64.800
13	44	78	20	70.200
14	46	79	20	71.100
15	47	80	20	72.000
16	48	81	20	72.900
17	49	81	20	72.900
18	50	81	20	72.900

and is also considered to be the maximum possible percentage of content damage in the distribution, corresponding to no reductions as a result of the warning. The maximum reduction in damages from column 4 is used to determine the minimum amount of content damages in the distribution The maximum reduction in damages at +2 is 30%.[30]

The distribution used in the sample is a simple uniform distribution. The minimum damage with the response system is estimated to be 11.9%[31], the maximum damage is 17%. For simplicity, assume any value in this range is as likely as any other.[32] A simulation using a uniform distribution would be expected to return a depth-damage curve roughly similar to the weighted curve in Table 5. The simulation results also reveal information about extreme value possibilities and the likelihood of curves equal to or greater than curves with specified values.

Another model, provided on the enclosed diskette, provides an example that uses the basic benefit model, described above, to estimate warning system benefits for a single structure using a depth-percent damage curve. Allowing warning time to vary uniformly from 1 to 24 hours, and using the same four response scenarios in application one, the benefits to a two-story residence with no basement are estimated to be $37.[33] The minimum estimate of benefits was $12, the maximum estimate was $69. In this example, without project condition expected annual content damage is $301 based on the FIA curve and a $100,000 home. Allowing the reductions from a warning system and the amount of warning time to vary, with project condition EAD range from $232 to $288 with a mean of $264.

Demonstrating the technique for one structure establishes the feasibility of estimating benefits for any number of structures by this technique Development of the software to do this was beyond the scope of this investigation so no community-wide estimate of benefits is prepared under this application. Existing models used by Corps Districts, particularly the models developed by the Hydrologic Engineering Center (HEC), could be modified to incorporate methods such as those modeled here should sufficient demand for such tools arise. The models presented here are inadequate for summing damages across many structures.

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[30]A maximum damage reduction of 30% means that 5.1% of total content value can be saved (i.e., 30% of 17%). The 30% estimate reflects the proportion of the population responding and the average effectiveness of their response.

[31]A 30% reduction in damage means that 70% of without-project condition damages is the minimum with condition damage. 70% of 17% is 11.9%. Hence, damages at +2 will range from 11.9% to 17%.

[32]Other distributions could be used. For example, a truncated normal distribution with a mean of 14.45% (the midpoint between 11.9 and 17), a standard deviation of 0.85% (divide the range by 6, the number of standard deviations needed to include about 99% of all observations), and a minimum value of 11.9% and a maximum of 17%.

[33]The small magnitude of the expected annual values reported here have no particular significance. The same rating and frequency curves used for earlier applications were used for this application. One foot below the first floor corresponds to the initial frequency point for the hydroeconomic model.

The approach for a commercial structure is similar. System benefits to commercial property based on standardized curves can be estimated in any of the ways indicated above. If commercial damages are estimated on the basis of interviews, the interviewer should collect information at the time of the interview that will facilitate the preparation of damage curves for different response scenarios.

CHAPTER 6
FURTHER CONSIDERATIONS

INTRODUCTION

The damage curve shifting framework has been presented, the literature has now been reviewed and the basic model has presented some alternatives for shifting the damage curve to represent the community's response to a flood warning and preparedness system. Many questions and issues remain for the analyst. A number of them are addressed in the following sections.

First, a few shortcuts, adapted from the experience of Corps personnel, that may be helpful in some cases are presented. The second topic covered is how to analyze a flood warning and preparedness system when it is only one component of a larger flood damage reduction plan. Third, suggestions are offered for when to use which of the applications present. The chapter concludes with the identification of some potential research topics.

SHORTCUTS

Despite the purported flexibility of the model presented here there will always be circumstances where a "seat of the pants" estimate is needed. Most experienced analysts have developed their own rules of thumb for providing these estimates. One of the most common techniques is "the similar areas method."

In the absence of any reliable data for a study area, it is a common practice to find an area as similar in the most important respects as possible and to use data from it. For example, suppose a warning system was evaluated for community A, roughly the same size and in the same basin as community B which is to be evaluated. A rough approximation of benefits for B may be obtained by multiplying the average benefits per structure of A by the number of structures in B.

For example, the Smallville warning system was estimated to produce $50,000 in expected annual benefits. There are 1,000 structures covered by the Smallville system. Tinytown, 70 miles downstream of Smallville, has 500 structures in its floodplain that would be served by a warning system. Using the $50 per structure average from Smallville, the Tinytown warning system benefits are estimated to be about $25,000 in expected annual benefits, based on the fact that it is a similar area that provides the best available data.

Per structure average EAD for a basin can provide a rough estimate of the total EAD for a community, if a structure count is available. With a rough estimate of EAD for the community and known annual costs of a warning system, one can work backwards to figure out what percentage reduction in EAD

is needed to make the system feasible. If the reduction seems reasonable[34], this may suffice as an indicator of economic feasibility.

For example, in the Dry Creek basin there are 10,000 structures in the floodplain, according to District files. The without-project condition EAD for all 10,000 structures is $1,000,000. This works out to be an EAD of $100 per structure. Tinytown has 500 structures, so its without-project condition total EAD is estimated to be $50,000.

A simple warning system for Tinytown has annual costs of $2,000. To justify this expenditure one would need at least a 4% reduction in damages. Is this reasonable?

Numbers like these are most useful for very rough estimates of economic feasibility. In the absence of numbers even this rough, it may be advisable to use some of the performance indicators mentioned in the opening of Chapter 4. Favorable comparisons[35] with communities where flood warning and preparedness has been justified or is being successfully used now may suffice in situations where budgets are so limited as to make most analysis impractical. The use of other indicators may be more useful in convincing local interests than in satisfying Corps' study requirements unless benefit-cost analysis requirements are waived or revised for low budget studies of warning systems.

FLOOD WARNING AS A COMPONENT OF A PLAN

In some planning settings, flood warning and preparedness systems may be the only alternative under consideration. When this is the case, benefit estimation can be conducted as outlined in this report. In other circumstances, a warning system may be one component of a larger flood damage reduction plan. Indeed, it may be an insignificant part of the larger plan. No matter which setting the analyst considers, the basic approach is the same.

In Chapter 2, the basic hydroeconomic model was reviewed. Any flood damage reduction alternative will affect either the damage, rating or frequency functions. Warning systems generally can be shown to shift the damage curve.

It is a simple matter to include shifts in the damage curve attributable to a warning system with a shift in the rating curve attributable to a channel improvement. In fact, it is not uncommon to have more

[34]Of course the definition of reasonable is the key here. As always, it goes without a precise definition. What is reasonable will be defined as a result of the normal negotiation process among the many parties to the study, its review and implementation.

[35]For example, it may be compelling evidence to identify a town with a system that is known to have prevented substantial damages and injury and to point out that it serves only half the number of people the proposed system would. Other indicators can be used similarly to try to develop favorable comparisons.

than one of the three basic relationships affected by a plan. The effects of a warning system can be easily and straightforwardly incorporated into the calculation of with project condition EAD.

WHAT LEVEL OF DETAIL IS APPROPRIATE?

Common sense rules in determining the appropriate level of detail for a flood warning and preparedness benefit evaluation. Four levels of detail that may be appropriate under varying circumstances are distinguished. Proceeding from the least to the most detailed these levels are: 1) Unit values; 2) Shifting existing damages curves; 3) Estimating response-dependent shifts of the damage curve; and, 4) Modification of individual damage curves.

The relevant circumstances include reporting requirements of the study and budget constraints. If a benefit-cost analysis is not required, other performance indicators can be used to evaluate a system. In most cases, however, a benefit-cost analysis will be required and that is our working assumption. The most common constraint will be that imposed by a limited budget.

Figure 29 shows the correlation between the available budget and the preferred level of detail. Predictably, the more available budget the more detail should be vested in the analysis.

FUTURE RESEARCH

Six different research topics are suggested below. They are italicized to make them easier to identify.

Individual districts may benefit by culling the information from their own files to develop a unit value data base. Estimating warning benefits or estimating without-project condition EAD on a per structure or per acre basis for different river basins could facilitate most general level screening evaluations within a district. *Research is needed to prepare a compilation and summary of existing warning system benefit estimates on per structure and per acre bases.* Compiling these values for all systems that have been evaluated will help Corps' planners and analysts determine reasonable parameters and unit value estimates in their planning activities.

Methods for developing detailed individual structure damage curves are well established. No further research is required in this area. The only real constraint on this level of analysis is budget. There must be funds available to finance the considerable data collection tasks associated with this approach.

Research is needed for those levels of detail between the most general and the most specific. Analysts need guidance in making reasonable judgments about the behavioral responses of people to warning systems. *Research is needed to prepare a comprehensive review of the literature related to behavioral response, summarizing the quantitative estimates of these responses in a concise way for use by Corps' planners and analysts.* The literature reviewed here only begins the process.

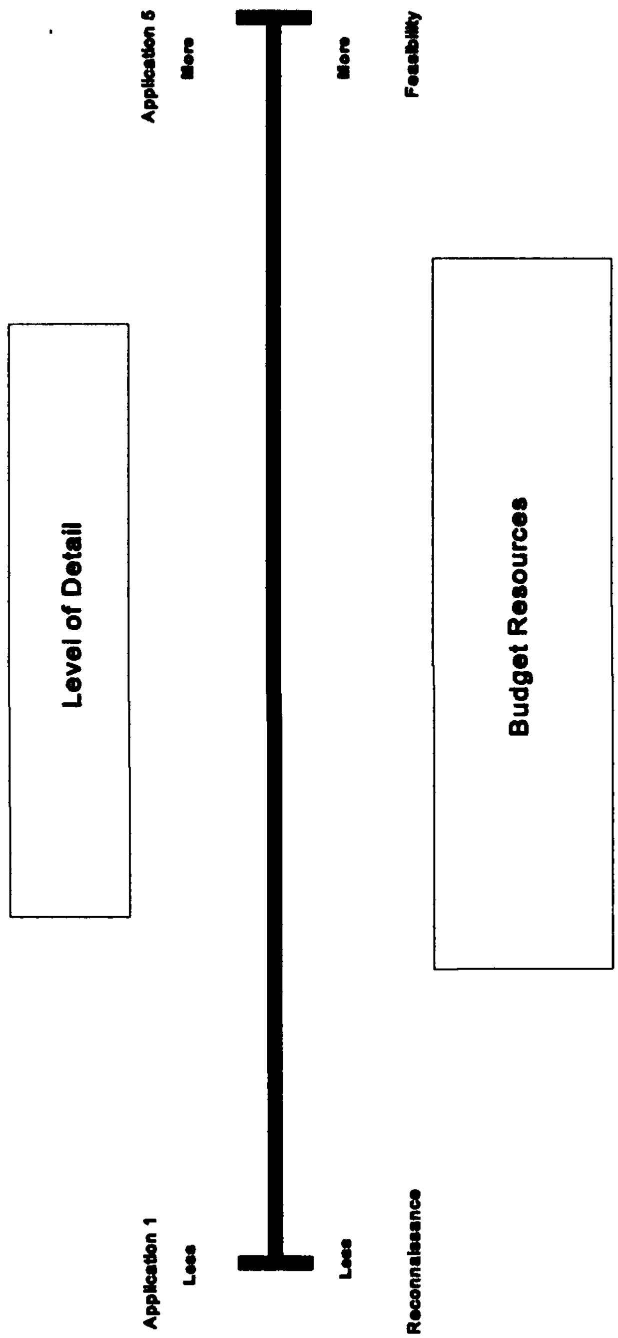

Figure 29
Level of Detail and Budget

Primary research is needed to determine in more precise terms what actions people take between the time they receive a warning and the time they evacuate. This information is needed to help determine the nature of the shift in the damage curve.

Research is needed to develop analytical tools that can be made available to all Corps' personnel. For example, the HEC-developed SID-EAD program could be modified along the lines of the model presented here. The models presented here are regarded as suggestions to be used, adapted and improved by Corps' analysts. At present, these models are available only to those with the requisite hardware and software. This situation must be corrected.

Research is needed to extract the maximum utility from data collected in recent IWR research efforts for use in evaluating flood warning and preparedness plans. For example, content surveys of homes in Wilkes-Barre, Pennsylvania may provide useful information in determining the types of contents that could be potentially removed from a home or moved to higher elevations during a flood alert. The value of these contents could be calculated as a percent of total content value and the results used to assist planners in evaluating systems at less detailed levels of planning.

Research is needed to establish a method for explicitly planning for the behavioral response of the public in the development of a flood warning and preparedness plan. The literature shows time and again that the benefits of a system depend on what the people do. Most flood warning and preparedness plans focus on the development of floodplain maps, forecasting hardware and software, communications technology, etc. Planning too often stops at the point where a reasonably reliable forecast of the timing and crest of a flood can be provided.

What is done with that forecast is rarely the focus of planning efforts, yet the true value of a system lies in what is done with the forecast. It is evident that local authorities must be actively and intimately involved in the preparation of this part of the plan. Plans must be expanded to include matters such as message content, message dissemination by multiple media, providing for confirmation of warning messages, considering a community's special needs such as the elderly or single mother populations, the prevalence and attitudes about pets, and whatever else is important to the community.

Case studies would be helpful in demonstrating the feasibility of changing the way flood warning and preparedness plans are developed. The reason for doing this is twofold. First, the literature suggests that it will improve the performance of the plan. Second, it may increase the benefits of a system.

APPENDIX 1
ESTIMATES OF BEHAVIOR RESPONSE PARAMETERS

Chapter 3 reviewed some of the warning response literature to identify broad types of behavioral response. In Chapter 5, a simple model for use in modeling response behavior was introduced. In this appendix, the literature is revisited to obtain some quantitative estimates of behavior. These estimates help provide a range for some of the behavior responses when no better information is available for a site. This report does not provide a comprehensive review of the literature and the reader is encouraged to further research the literature for behavioral responses of interest to him.

Bearing in mind the ultimate goal is to shift the stage-damage curve in a manner that represents the community's response to warnings for a range of floods, a common starting point for many warning response studies is to consider how many people hear the warning. Some time is spent discussing the first results presented and how they might be used. Subsequent summaries of the literature are offered without the discussion and examples because the general approach to using the literature will be identical.

Leik, Carter, and Clark (1981) have provided one of the few quantitative descriptions of pre-evacuation behavior available from the literature. The authors studied three hurricane sites (Miami, Mobile, and New Orleans), eight flood sites (Atlanta, Boise, Wheeling, Sedona, Rochester, Clarksburg, Palo Duro, and New Orleans), and four tornado sites (Tupelo, Tulsa, Council Bluffs, and Minneapolis-St. Paul). The percentages of respondents who were aware of the official warning before the event by community were for hurricanes 97.4, 97.8, and 92.5 percent; for floods 80.5, 41.5, 72.7, 63.4, 88.8, 38.4, 22.7, and 15.0 percent; and, for tornados 38.4, 71.3, 90.8, and 81.0 percent.

The implications of these results for analysts could be many. First, it appears that it is reasonable to assume a higher percentage hear warnings for hurricanes, all other things equal. The number hearing the flood warning is quite variable, however. To use these results in a reasonable manner it makes sense to go back to the original documents to determine the characteristics of the high response and low response communities. Comparing one's study area to those in the literature, it is easier to determine which response is more likely.

Most post-disaster reports and articles are oriented toward determining what went right and what went wrong. There are many lessons to be learned from the literature. Planning a flood warning and preparedness system should include a heavy emphasis on the behavioral aspects of the plan. The literature provides a rich source of mistakes to avoid and, concomitantly, a rich source of suggestions that will help ensure a higher response rate, including a larger percentage hearing the warning.

Leik et al's results can be used to provide an example of how the literature can be used to develop parameter estimates for the benefit analysis. Assume a benefit estimation approach similar to that of Application Three in Chapter 5. The number of people who hear the warning can be estimated based on data obtained directly from the community. The number of households that have heard warnings in the past

are a prime source of such information; residents can be surveyed to determine their likely behavior.[36] Systems can be designed to maximize the likelihood that people will hear the warning. Such plans require some knowledge of the community's formal and informal communication networks (i.e., do they listen to radio? watch TV? gather at the general store?).

In the absence of better data, the literature can be used to help estimate the response. The ideal approach would be to conduct a thorough search of the literature relating to the analyst's concerns. The review presented here should provide a fruitful starting point for most such searches. By reviewing the source documents, it should be possible to determine which results in the literature are most applicable to the analyst's study area.

For the sake of an example, let us assume that Leik et al's flood area results are applicable. One could use the mean of the eight communities, 53.0%. Using this number ignores a lot of information, specifically the variation that was observed in different communities. One could take the minimum (15.0%) and the maximum (88.8%) and define a uniform distribution. By adding the mean to the minimum and maximum a triangular distribution can be defined. Taking the eight communities as a sample, one could calculate the standard error and use it and the mean to describe a normal distribution. It may be desirable to truncate the normal distribution at a lower value of 0 and an upper value of 1.0. There are any number of other distributions that could be used, including cumulative distributions designed by the analyst to include information from the literature and the community. No matter how the literature is used, a reasonable effort must be made to ensure some comparability of circumstances or a clear description of the limitations of the analysis.

The surveys further indicate that the percentages of survey respondents who initially took action at the hurricane sites were 41.5, 39.9, and 27.1; at the flood sites the percentages were 7.9, 8.8, 13.0, 11.1, 13.6, 16.6, 19.7, and 9.8; and, at the tornado sites 9.4, 21.8, and 4.5% took action. The response to hurricane warning appears to be more immediate than to floods or tornados. In the absence of site-specific data, this information from the literature can serve as a starting point for estimating the response or range of responses from any individual community, bearing in mind that these data represent the initial response only and do not reflect the total numbers that eventually took action.[37] Thus, these values represent minimum numbers of people who took action to minimize damages.

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[36]The discussion of sampling contained in the appendix is as applicable for a sample designed to determine behavioral responses to floods as it is for conducting a damage survey.

[37]Suppose we want some kind of idea how many people will take some kind of action in response to the warning, but have no budget for a site-specific survey of past or likely future behavior. Using data from the flood sites we see the minimum response observed was 7.9% and the maximum was 19.7%. The weighted average (using the number of respondents from each community as the weight) is 13.5%.

Planners could look at the list of communities, investigate the circumstances of flooding and assume their community is like one of those previously studied and use that percentage. Alternatively, planers could say the actual response will lie somewhere between 7.9 and 19.7% with a most likely response of 13.5%. These three parameters describe a triangular distribution that can be used in models such as those described in this report.

The actions that people reported taking do not always lead to reductions in flood damages, however. A more detailed study of the actions taken in the hurricane sites revealed the most common action was to turn on the radio or TV. Gathering food and supplies, securing objects and putting gas in the car were the next most common actions taken. Taping windows, turning utilities off, calling the weather service and doing nothing were other responses. Damage-reducing actions could fall under the category of "Other" protective actions taken. In New Orleans, Miami, and Mobile 16.7, 13.2, and 22.8% of the respondents took other actions not specified.

The work by Leik et al contains a large number of tables summarizing the findings of the authors in 15 communities. These tables provide some quantitative information on differences in response to warnings by age, family status, and risk perception.

Ferrel and Krzysztofowicz (1983), summarizing information from prior studies of Victoria, Texas, Tucson, Arizona, and Shrewsbury, England found that 19, 24, and 43% of surveyed floodplain occupants made some partial response to the warning by elevating possessions, moving their cars, sandbagging, etc.

The percentage of people whose initial response to the hazard warning was to take action, ranged from a low of 4.5 to a high of 41.5%. These were the people with the most time available to them to take effective damage-reducing action.

The Illinois Department of Transportation (1985) has reported that 60% to 80% of the people in a threatened area will take some type of protective action the first time a flood warning is issued. If a flood occurs, the percent responding will increase to about 90%-95% with the next flood. Hence, experience is important.

Perry et al (1981) provide numerous summaries of response behavior in four communities during floods. Table 6 provides an example of the type of information available in this report. Dividing floodplain occupants into five groups based on their perception of the flood threat ranging from "totally disbelieved" to "totally believed", the authors looked at three responses: followed normal routine, took protective action, and evacuated. These results show that 17.3% followed their normal routine, 33.1% took protective action and 49.6% evacuated.[38] Perry et al provide an excellent source of quantitative information on evacuation rates and other types of behavioral responses.

Parker and Rowsell (1981) have done a great deal of research in the area of quantifying the indirect benefits of flood damage reduction in general and flood warning and preparedness systems in particular. Table 7 summarizes some of their research results presenting the indirect costs of flooding as a percentage of total flooding costs. Though the method has been largely abandoned, it may be cost effective to use a fixed ratio between direct and indirect flood losses in some low budget studies. Building on the work summarized in Table 6, Parker, Green and Thompson (1985) present additional ratios. They have also done work on manufacturing firms that found:

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[38]These figures represent the sum of all normal routine rows, protective action rows, etc. divided by the total of 538 responses.

Table 6
Perception of Threat By Warning Response
(in percentages)

Site	Warning Response	Totally Disbelieved	Somewhat Disbelieved	Moderately Believed	Largely Believed	Totally Believed
Sumner	Normal routine	55.6	71.4	20	5.6	8.6
	Protective action	11.1	28.6	50	33.3	22.4
	Evacuated	33.3	0	30	61.1	69
Valley	Normal routine	75.0	41.7	20	0	12
	Protective action	0	41.7	40	51.9	27.8
	Evacuated	25	16.7	40	48.1	60.2
Fillmore	Normal routine	0	44.4	21.4	26.3	6.9
	Protective action	0	55.6	46.4	21.1	19
	Evacuated	0	0	32.1	52.6	74.1
Snoqualmie	Normal routine	50	53.3	35	3.6	13.1
	Protective action	50	26.7	45	64.3	34.5
	Evacuated	0	20	20	32.1	52.4

Table 7
Indirect Damages
As % of Total Damages

LOCATION	RETURN PERIOD YEARS	PERCENTAGE
Whitstable, UK	12.0	4.70
	20.0	6.90
	40.0	4.70
	80.0	4.80
	150.0	4.80
	300.0	4.60
	1,000.0	4.40
Chesil, UK	.5	93.40
	5.0	43.20
	50.0	48.10
Pulborough, UK	5.0	53.00
	12.0	54.00
	50.0	40.00
Ashton Vale, UK	40.0	21.00
Towcester, UK	2.0	18.00
	3.0	13.00
	5.0	11.00
	10.0	9.00
	50.0	8.00
	70.0	7.00
	75.0	7.00
Gillingham, UK*	4.0	.90
	8.0	5.57
	12.0	3.09
	25.0	2.62
	50.0	1.49
	100.0	1.06
Swalecliffe, UK *	3.0	5.49
	5.0	7.32
	15.0	6.75
	24.0	8.17
	37.0	10.87
	114.0	12.26
	250.0	19.47
Forbes Sire, AUS *	20.0	1.17
	100.0	3.72

* From Parker, Green and Thompson (1985). All others from Parker and Rowsell (1981)

"The ratio of indirect to direct national losses is 12.7% at 1 meter flood depths.."

Estimates of indirect flood losses for manufacturing firms have also been estimated in British pounds on a square meter basis. Using this exchange rate for that period Table 8 converts Parker et al's finding (1985:16) to US dollars.

Table 8
Flood Losses Per Square Meter
For Manufacturing Firms (1/84)

	Floodwater Depth in Meters			
Mean Loss Category	0.15	0.30	0.60	1.00
Direct	$ 24.88	$ 53.87	$ 91.73	$128.73
Indirect Firm	10.47	14.57	26.61	30.06
Indirect Region	9.02	12.18	21.22	24.00
Indirect Nation	7.00	8.55	14.98	16.38

As far as the damage-reducing effects of peoples' response to flood warnings, little has been done. Pennington-Rowsell and Chatterton (1979) wrote what amounts to a handbook that far surpasses any other single work on the estimation of inundation reduction benefits. They have identified the likely damage-reducing actions taken with different lengths of warning time (p.32). These are not reproduced here. The contents differ significantly from what might be found in an American home; in part, because of cultural differences but more importantly because of technological changes since the original data were collected.[39]

[39]VCRs, Nintendo, compact disk players, microwave ovens, and personal computers are a few of the more obvious examples of changes in contents since the late 1970s.

That information would provide an excellent starting point for anyone trying to develop empirical estimates of damage reductions. Preceding this information in Pennington-Rowsell and Chatterton's report (pp. 30, 31) is an example of how a depth-percent damage curve could be estimated for either the without or with project condition.

Pennington-Rowsell and Chatterton (1979:29) report that the value of potential damage saved for residential properties is:

> "..in the order of 3% of property value per hour of warning up to 4 hours."

Using these as default values results in, say, a 0 to 3% reduction in damages with one hour of warning; a 0 to 6% reduction with two hours of warning, etc.[40]

Neal and Parker (1989) conducted surveys of a number of flooded areas to determine the response to flood warnings. Of those who were warned and subsequently flooded, 50 to 75% of the people reported moving property. Of the people without flood experience, 50% feel they would be able to do something, while 80% of those with experience said they would do something to reduce damages.

Those who indicated they would not move things were asked why. Ten percent said other actions are more important, 39% are physically unable, 28% felt it would not be necessary, 3% felt it would not be effective, and 20% gave other reasons. Thus, the percent of people taking action could arguably be increased in areas where the physically limited are few in number. Likewise, plans that provide the type of education and training that would lessen the numbers of people thinking action is unnecessary or ineffective will also have more people taking effective action to reduce damages.

In 1976, Day and Lee estimated benefits for warning systems for a few scenarios. Of potential interest is the fact that their study provides estimates of reducible damages per structure for residential, trailer and commercial properties; and reducible damages per acre for the same property types. Thus, in the absence of any better data the literature provides some per structure and per acre estimates. These estimates are dated and of limited applicability and are not reproduced here.

Krzysztofowicz and Davis define three values for a flood warning and preparedness system. The first is **actual value** (AV); this is what Corps planners would consider the best estimate of benefits for a forecasting system. The second is **optimal value** (OV) and it represents the benefits that would accrue if every individual decision maker (i.e., each resident, business manager, etc.) in the floodplain made an optimal response to the warning given. The **potential value** (PV) represents benefits that would result from perfect forecasts and optimal responses to these perfect forecasts. PV > OV > AV is considered to be

[40]The ranges presented are examples only. It may be reasonable to expect two hours warning to provide say 3 to 6% reductions. If a model like the response model of Chapter 4 is used, this percent reduction must be weighted by the number of people who are expected to undertake damage-reducing activities.

true by definition. It may be helpful to estimate these different values to aid the decision making process. The PV and OV provide upper limits on the potential benefits.

The authors go on to define three efficiency concepts. **Forecast efficiency** (FE), a measure of how well the forecast system meets the needs of the response system[41], is defined as OV/PV. **Response efficiency** (RE) is a measure of how well the response system is utilizing the forecasts it obtains and is defined as AV/OV. **Total efficiency** (TE), is AV/PV, or FE times RE. These values must be less than or equal to one and higher values indicate more efficient systems. The efficiency values provide an alternative to benefit-cost or monetary-based evaluation criteria. Differences in warning times among warning system alternatives can be evaluated in terms of the changes in system efficiencies.

RECENT IWR RESEARCH

We have indicated a need for additional research to aid analysts in dealing with behavioral responses to warning systems. It is worth noting that IWR has taken the most significant step forward in this area that has been taken. Comprehensive surveys of communities in West Virginia, Kentucky, Pennsylvania, and Texas have been undertaken for a number of research efforts. These surveys may yield a bonanza of data for use in evaluating warning systems.

Of particular value to planners and analysts were the recent surveys of the West Virginia and Kentucky communities. The survey of businesses in these communities asked a number of questions that are of direct interest to evaluating flood warning systems. The percent of people who received a first warning is available (Question 6 of the OMB-approved survey form), as is a rather detailed description of the behavioral response to the first warning message (Question 12). Respondents are probed on the receipt and response to second warnings as well as their reasons for their response. The surveys also probed for the costs of responding to the flood threat and the potential savings realized from hypothetical warning times (Questions 58-61).

For example, the Kentucky business survey indicates that 94.6% of the respondents received the first warning message. About 48.6% elevated valuables, files or furniture as a response to the first warning. Considerable detail is provided on other response behaviors. Similar questions were asked of residential floodplain occupants as well.

These data represent a valuable resource to any planners or analysts working in the evaluation of flood warning and preparedness systems.

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[41]The authors work within a flood forecast response process framework that consists of a forecast system involving the technical aspects of the system and the response system which deals with decision makers' responses to the warning.

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13. ABSTRACT *(Maximum 200 words)*
THIS REPORT PROVIDES A CONCEPTUAL FRAMEWORK FOR PLANNERS TO EVALUATE BENNEFITS ACCRUING TO FLOOD WARNING AND PREPAREDNESS ALTERNATIVES AND TO DEMONSTRATE METHODS SUITABLE FOR ESTIMATING THESE BENEFITS UNDER A VARIETY OF PLANNING CIRCUMSTANCES. THE REPORT SUMMARIZES DEMOGRAPHIC FACTORS AND SYSTEM ATTRIBUTES THAT CONTRIBUTE TO FLOOD WARNING RESPONSE. THE SPECIFIC ACTIONS THAT CAN BE TAKEN FOR REDUCING FLOOD DAMAGES IN AN EMERGENCY SITUATION ARE DESCRIBED ALONG WITH A TAXOMONY OF THE RESULTING BENEFITS. THE REPORT INCLUDES PROCEDURES OF VARYING LEVELS OF DETAIL FOR CONDUCTING RISK-BASED ECONOMIC ANALYSIS OF FLOOD WARNING AND PREPAREDNESS SYSTEMS.

14. SUBJECT TERMS
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